APPENDIX F

COMPUTER MODELING

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

PAGE

TABLES

TABLE OF CONTENTS (Cont'd)

PAGE

FIGURES

PAGE

FIGURES

TABLE OF CONTENTS (Cont'd)

PAGE

FIGURES

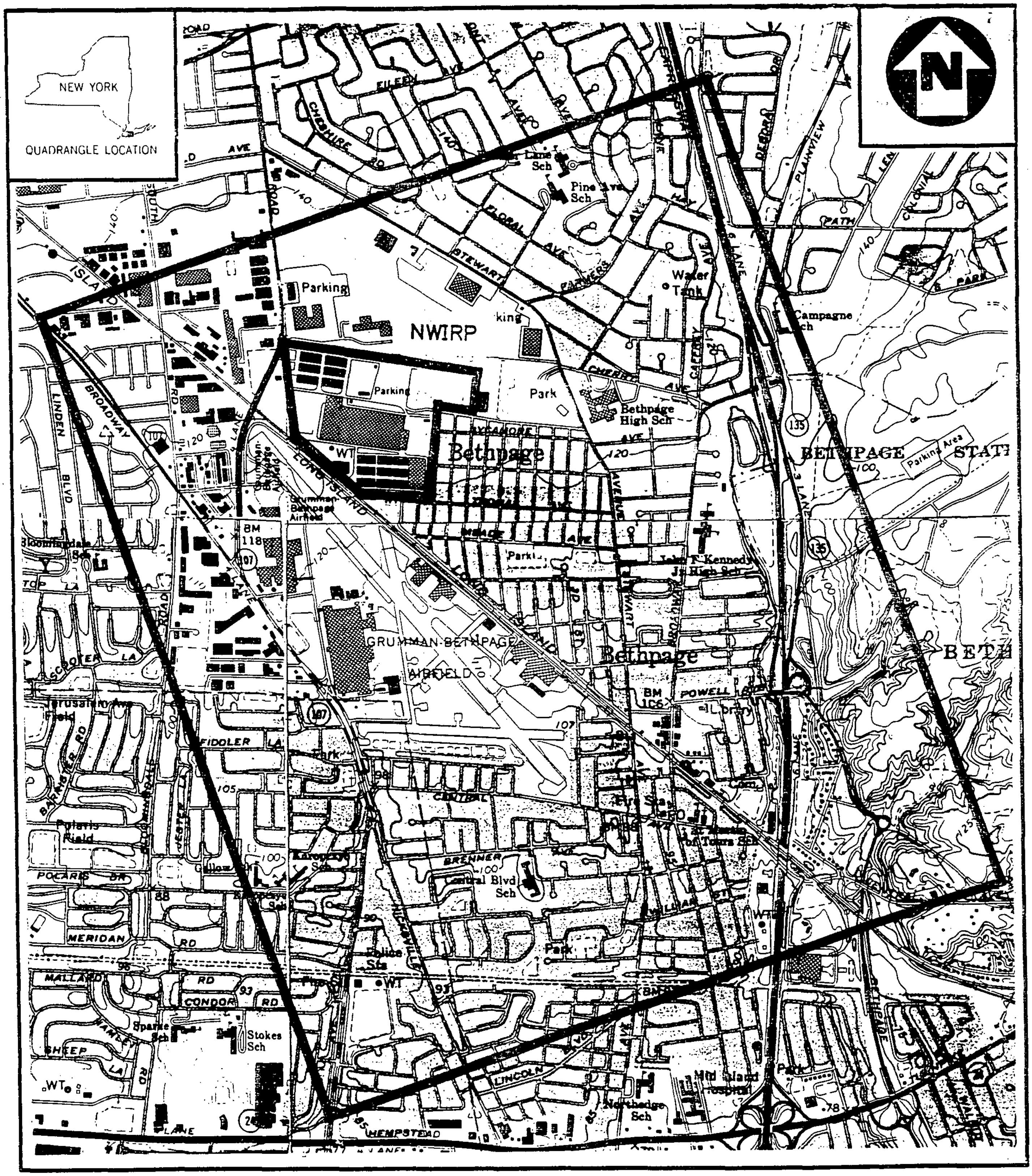
PAGE

FIGURES

TABLE OF CONTENTS (Cont'd)

PAGE

FIGURES



LEGEND

EXTENT OF MODEL GRID

0 2000 4000

SCALE IN FEET

FIGURE 1-1

LOCATION OF
FINITE DIFFERENCE GRID BOUNDARY
BETHPAGE, NY

HALLIBURTON NUS
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ACAD: 1953\LOCMAP.DWG 6/8/93 MB (LOCPLOT)

1.0 INTRODUCTION

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This Appendix of the RI report presents the overall approach and the results of the Computer Modeling efforts performed at Bethpage Naval Weapons Industrial Reserve Plant (NWIRP) at Bethpage New York, which were conducted for the U. S. Navy.

Bethpage NWIRP is located on 108 acres in Nassau County of Long Island, approximately 20 miles east of New York City in a highly industrialized area. Grumman Aerospace Corp. (Grumman) leases property from the U. S. Navy as part of its Aerospace manufacturing activities. Figure 1-1 shows the location of the NWIRP site. The histories of the NWIRP and Grumman facilities are discussed in detail in the Initial Assessment Study of the NWIRP and the RI/FS Work Plan prepared by Geraghty & Miller.

Grumman utilizes 14 high capacity production wells located on the facility for air conditioning and non-contact cooling purposes. Water pumped from these wells is returned to the aquifer via several recharge basins located across the site. The Bethpage Water District (BWD) operates water supply wells to the east and south of the Bethpage NWIRP.

1.1 OBJECTIVES OF THE COMPUTER MODELING

The modeling investigation is part of an overall RI/FS program designed to determine the locations of any potential sources of contamination on U. S. Navy property.

The general objective of the computer modeling was to provide data on groundwater flow in the area of the NWIRP and the potential flow directions of contaminants. The specific objectives of the RI computer modeling at Bethpage NWIRP are listed below:

- To provide a general characterization of the subsurface conditions underlying Bethpage NWIRP,
- To develop a localized flow model which accurately represents groundwater flow in the area around the Grumman site, with an emphasis on the groundwater flow in and around the NWIRP, and

DRAFT

- To model the flow directions and rate of travel for simulated contaminant releases under a variety of production well and recharge basin pumping conditions.

As part of the FS program for the NWIRP, additional computer modeling will be conducted. Objectives for the FS phase of modeling include

- Utilizing the calibrated flow model to determine potential contaminant transport directions, and
- Using particle tracking and contaminant transport simulation for evaluation of remedial alternatives for the site.

1.2 ORGANIZATION OF COMPUTER MODELING REPORT

This appendix summarizes the development of the RI computer modeling efforts and presents their results. The report is organized into nine sections. Section 1 provides an introduction to the computer modeling. Section 2 summarizes the hydrogeologic conditions of the site area. Section 3 discusses the modeling approach. Section 4 discusses the conceptual model. Section 5 summarizes computer code selection. Section 6 discusses model calibration. Section 7 discusses model validation. Section 8 discusses the particle tracking performed at the site. Section 9 summarizes the sensitivity analysis performed for the site. Section 10 provides a summary of modeling activities and a discussion of model limitations.

2.0 HYDROGEOLOGIC CONDITIONS

Bethpage NWIRP is located in west-central Long Island, which is underlain by approximately 1,100 ft of unconsolidated sand, silt, clay and gravel sediments of Late Cretaceous and Pleistocene age. These unconsolidated sediments are underlain by Precambrian crystalline bedrock, which slopes to the south-southeast. All of the geologic units dip in these directions to varying degrees (Isbister, 1966). Three aquifer systems are present within the unconfined sediments. In descending order these are, the upper glacial aquifer, the Magothy aquifer, and the Lloyd aquifer.

2.1 AQUIFER CHARACTERISTICS

2.1.1 Upper Glacial Aquifer

The upper glacial aquifer is composed of fine to coarse sand and gravel outwash deposits. In the modeled area, this unit is the upper-most hydrogeologic unit. This unit ranges in thickness beneath the site, with a total thickness of less than 75 ft. Literature sources estimate hydraulic conductivity values of approximately 270 ft/d and vertical hydraulic conductivity values at approximately one-tenth of horizontal conductivity (Smolensky and Feldman, 1990). In the majority of the area encompassed by the modeling grid, the water table lies below the bottom of the upper glacial aquifer.

2.1.2 Magothy Aquifer

The Magothy aquifer is composed of fine to medium sand, with many discontinuous clay lens present throughout the aquifer. Fine grained sediments are common in the Magothy aquifer, although no clay lenses of regional extent were encountered during the drilling program at the site. The lithologic trend observed during drilling is a decrease in the average grain size with increasing depth. The Magothy aquifer has a reported thickness of approximately 600 feet beneath the NWIRP. The basal portion of the Magothy aquifer is reported to consist of a highly permeable and productive gravel (Isbister, 1966; Geraghty & Miller, 1990).

Horizontal hydraulic conductivities for the Magothy aquifer have been estimated at approximately 50 ft/d, with decreasing vertical hydraulic conductivity with depth compared to the upper glacial aquifer. Anisotropy has been estimated at approximately 100:1 (Smolensky and Feldman, 1990). The upper portions of the aquifer are unconfined with an increasing degree of confinement with depth (Isbister, 1966). The Magothy aquifer is the principal water-supplying aquifer for the Grumman production wells and BWD wells. Water returned to the aquifer from the recharge basins at the NWIRP is believed to move through the upper glacial aquifer and recharge the Magothy aquifer, which contains the water table across much of the modeled area. The Magothy aquifer and the upper glacial aquifer are regarded as a common aquifer because they have similar lithologies, and no barrier to downward flow exists between these units.

2.1.2 Raritan Formation

The Raritan Formation underlies the Magothy Formation, and the Lloyd Sand Member of the Raritan Formation represents the third significant water bearing system in the area. The Lloyd Sand is separated from the Magothy aquifer by the Raritan Clay unit, which represents the first regionally extensive barrier to downward movement of groundwater. The Raritan Clay may range in thickness up to 175 feet thick, with vertical hydraulic conductivities of approximately 0.001 ft/d (Smolensky and Feldman, 1990; Isbister, 1966). Due to the thickness and very low conductivity of the Raritan Clay, and the fact that the Lloyd sand is not a major source of public water, the top of the Raritan Clay is considered to represent the bottom of the groundwater flow system for the area around the NWIRP.

2.2 GROUNDWATER FLOW

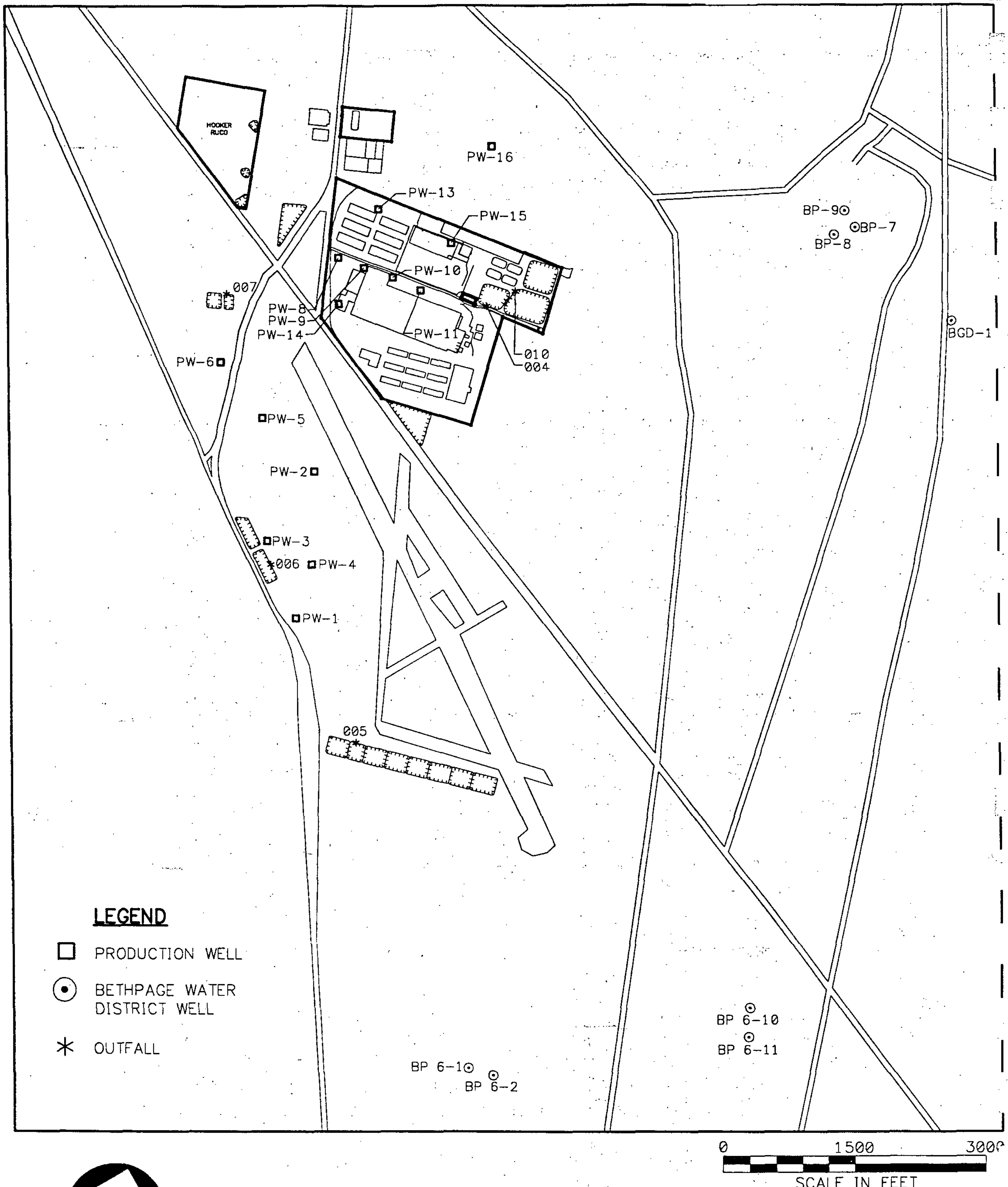
Most of Long Island is bisected by a east-west trending, regional groundwater divide. The NWIRP lies to the south of this divide. The groundwater beneath the NWIRP predominantly flows in a southward direction (towards the Atlantic Ocean), although the flow directions are greatly influenced by the groundwater mounding which occurs at the recharge basins associated with Grumman activities. In addition, groundwater withdrawal from Grumman production wells have a pronounced influence on groundwater flow directions. The production wells and recharge basins operate in various pumping combinations which makes their effect of local groundwater flow direction subject to change. The NWIRP occupies an area of recharge with vertical hydraulic gradients having a downward direction (Isbister, 1966).

2.3 GRUMMAN PRODUCTION WELLS AND RECHARGE BASIN ACTIVITIES

As part of Grumman activities, fourteen production wells are operated for non-contact cooling and air conditioning purposes. Numerous recharge basins located around the site recharge water pumped from the production wells to the aquifer system. Figure 2-1 illustrates the location of Grumman production wells and recharge basins. Prior to 1984, some Plant 03 production-line rinse waters were discharged directly to the recharge basins and may have contained chemicals involved in the manufacturing process.

Interviews with Grumman personnel indicate that water pumped from production wells to recharge basins follows a consistent pattern. Production wells PW-8 through PW-16 are north of the Long Island Railroad tracks, which bisect Grumman property. Water produced from these northern production wells is recharged to northern recharge basins (outfalls 004 and 010). Water derived from southern production wells, PW-1 through PW-6, is recharged via southern recharge basins (at outfalls 005, 006 and 007). Monthly records of total pumpage from these wells has been recorded by Grumman, and this monthly pumpage data was used as part of model calibration and model validation. The majority of water pumped by Grumman production wells is returned to the aquifer by recharge basins, although a loss of water may occur due to evaporation from the recharge basins and water diverted off site to sewers and water treatment plants.

The total amount of production well pumpage and basin recharge is cyclic with an increase in summer months when demand for cooling is greatest and a decrease in the winter. Pumping data provided by Grumman indicate that production wells pump a minimum amount during February and a maximum amount during August. Production well rates may be as high as 1,200 gpm.



LOCATION MAP OF
GRUMMAN WELLS, BWD WELLS
AND RECHARGE BASINS
BETHPAGE, NWIRP

FIGURE 2-1

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3.0 SUMMARY OF MODELING APPROACH

3.1 DATA COLLECTION / ANALYSIS

The first portion of the modeling process is to compile the existing data. The available, relevant data regarding site hydrogeologic conditions and groundwater quality was collected and reviewed. Groundwater elevation data, meteorological conditions, pumping and recharge data, and well location data that was required for model activities was identified and obtained from Grumman, state, and Federal sources. To more fully define the aquifer parameters at the site, two pumping tests were conducted at the NWIRP. For pumping test #1, the intermediate well HN-27I2 was pumped at 448 gpm, and drawdown was measured in 10 observation wells. For pumping test #2, the deep production well PW-11 was pumped at 890 gpm and drawdown was measured at 9 observation wells. A complete discussion of the results and analysis of the pumping tests is discussed in Appendix E.

3.2 CONCEPTUAL MODEL DEVELOPMENT

A conceptual model of the groundwater system was developed from information gathered after the data collection phase. The conceptual model identified and incorporated the key hydrogeologic characteristics at the site, potential contaminant source information, and locations of the BWD water supply wells in the area. In addition, the rationale for assumptions and simplifications made to the natural site conditions were reported and described in the conceptual model.

3.3 COMPUTER CODE SELECTION

A groundwater flow modeling code was selected for the modeling project. The computer code selected for the project must be able to incorporated the key aspects of the conceptual model, and must have been well tested and verified. In addition, particle tracking and contaminant transport applications must be supported by the groundwater flow model.

3.4 FLOW MODEL CALIBRATION

The site wide flow model was developed by configuring the conceptual model into a format which is compatible for input into the flow model and entering initial values for aquifer parameters into the flow model. The model was then calibrated for two steady-state pumping conditions, and two transient pumping test simulations. The flow model was calibrated by adjusting initial values of parameters, such as, vertical and horizontal hydraulic conductivities, storage and boundary conditions. Calibration continued until the water level elevations at 61 monitoring wells (in steady-state simulations) and the modeled drawdowns (in transient pump test simulations) were adequately comparable to measured values.

3.5 FLOW MODEL VALIDATION

The calibrated model was validated using two steady-state pumping conditions and resulting water elevations which were not previously used in calibration. For each month used for validation, the pumping/recharge rates of Grumman production wells and recharge basins were input into the model, and the model results were compared against the measured water level elevations at 61 monitoring wells.

3.6 PARTICLE TRACKING

Particle tracking was performed to determine the possible directions and rates of contaminant movement following a simulated contaminate release from potential sources. Particle tracking was performed under a variety of pumping and recharge conditions, from a variety of potential sources. This approach allows for several potential release scenarios to be examined. An analysis of the rate of particle movement and the three dimensional movement of particles throughout the aquifer was also conducted.

3.7 SENSITIVITY ANALYSIS

Sensitivity analyses was performed to determine how sensitive the model output is to changes in aquifer parameters. The sensitivity analyses involved changing aquifer parameters by incremental amounts and evaluating these effects on model predictions. The results were used to quantify model accuracy and model assumptions.

3.8 SUMMARY OF MODEL LIMITATIONS

All computer modeling simulations are subject to error due to simplifications in the model, which are necessary in order to simulate complex natural systems. The impact of these sources of error can be minimized by realizing what may contribute to error in modeling results and performing sensitivity analysis on the developed model. Potential sources of model error are identified, and the steps taken to minimize error are discussed.

4.0 CONCEPTUAL MODEL

After compiling existing data available for the site, a conceptual model was constructed for the site. The conceptual model identified and incorporated the key hydrogeologic characteristics at the site, including contaminant source data, BWD well information, and other factors which control groundwater flow.

The conceptual model for the study area is summarized in the following subsections which describe

- Areal and vertical extent of the model grid,
- Model Grid dimensions,
- General hydrogeologic conditions in the model area,
- Initial estimates of the hydrogeologic parameters, and
- Boundary conditions.

4.1 AREAL AND VERTICAL EXTENT OF THE MODEL GRID

The purpose of the modeling was to define the flow of groundwater in the area encompassed by the NWIRP, Grumman property, and in the surrounding area. Figure 4-1 shows the area being modeled, and the finite-difference grid used in this study. The location of the model grid was defined in order to maximize the grid density within Navy property and encompass the BWD wells to the east of the site (BP-7, BP-8, BP-9), the Hooker-Ruco site, and the southern extent of Grumman property.

The northern boundary of the model area is located approximately 2000 feet north of the NWIRP. This location was chosen because it encompasses all Grumman production wells and lies north of the Hooker-Ruco site. The east boundary lies approximately 4800 feet east of the NWIRP and was chosen to provide full coverage of the eastern BWD wells (BP-7, BP-8, BP-9). The western grid boundary lies approximately 600 feet west of the NWIRP and encompasses the Hooker-Ruco site. To the south, the boundary lies approximately 3000 feet south of the NWIRP, and was located to encompass all Grumman property and southern recharge basins. The model grid is oriented so the east-west sides of the grid boundary are parallel to the groundwater flow direction in the area.

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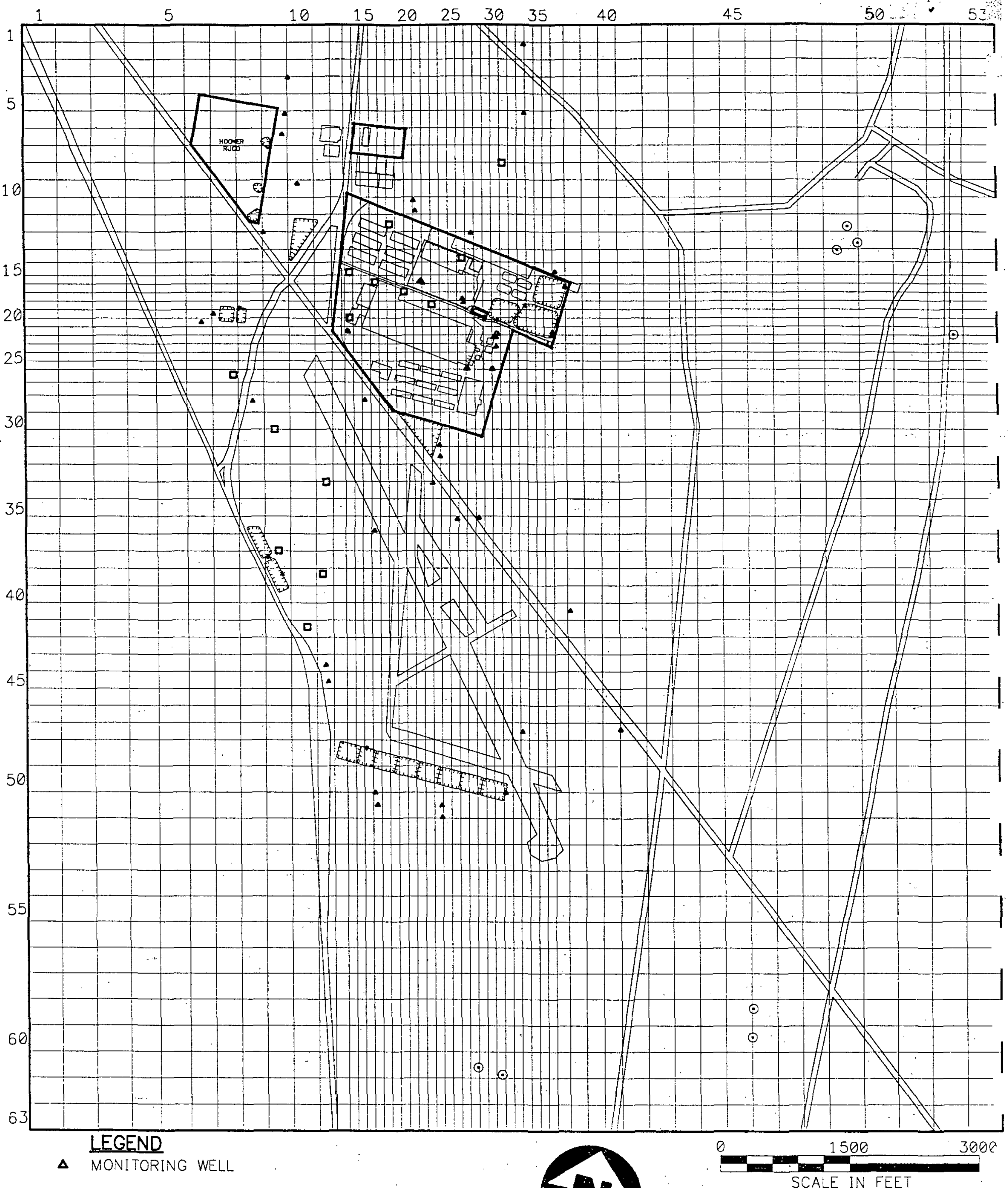

LEGEND

▲ MONITORING WELL

□ PRODUCTION WELL

⊙ BETHPAGE WATER DISTRICT WELL

* OUTFALL

FINITE-DIFFERENCE MODEL GRID BETHPAGE, NWIRP

FIGURE 4-1

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4.2 MODEL GRID DIMENSIONS

4.2.1 Horizontal Dimensions

The block-centered finite-difference grid for the site covers a 11,300 by 12,800 ft area, as shown in Figure 4-1. The grid consists of 53 columns and 63 rows and contains 5 layers. Grid line orientation was designed with columns parallel to the normal (non-pumping) groundwater flow direction in the area covered by the grid. Due to software and computer memory limitations, there are a finite number of nodes which can be effectively incorporated into a computer model. In areas of interest, nodes are more closely space to provide tighter coverage of that area, while larger node spacings are used outside the area of primary interest. Grid spacing has the highest density in the section of the grid which covers the NWIRP, where each node has a length and width of 100 ft. The consistently small size of the grid blocks allows for a detailed evaluation of potentiometric heads and groundwater flow in these areas. Node size increases towards the outer edge of the grid, where more widely spaced model generated heads were acceptable. All nodes of the grid are active (i.e., part of the aquifer).

4.2.2 Vertical Dimensions

The model grid consists of five layers, which are differentiated based on monitoring well depths in the modeling area. Layer 1 extends from the surface to approximately 100 ft below ground surface (bgs) and incorporates shallow HNUS monitoring wells. Layer 1 ranges in thickness from 77.5 to 105 ft. Layer 2 and 3 are each 100 ft thick. Layer 2 contains intermediate monitoring wells, while layer 3 contains deep HNUS monitoring wells and one BWD well. Layer 4 is 150 ft thick and contains some of the shallower Grumman production wells and one BWD well, while layer 5 ranges in thickness from 150 to 315 ft thick and contains the majority of the Grumman production wells and BWD wells.

This spacing of grid layers in relationship to well depths allows for a direct association between well depths and model layers. For example, a water table contour of the modeled heads in layer 1 would consist of shallow well heads, while a contour of layer 2 modeled heads would consist of intermediate well heads. In this way, contaminants can also be tracked throughout the aquifer. For example, if contaminants pass from layer 1 to layer 2 at a point with a shallow and intermediate well, the intermediate well would pick up the contaminations at that point, while a shallow well would be too shallow to pick up the contamination.

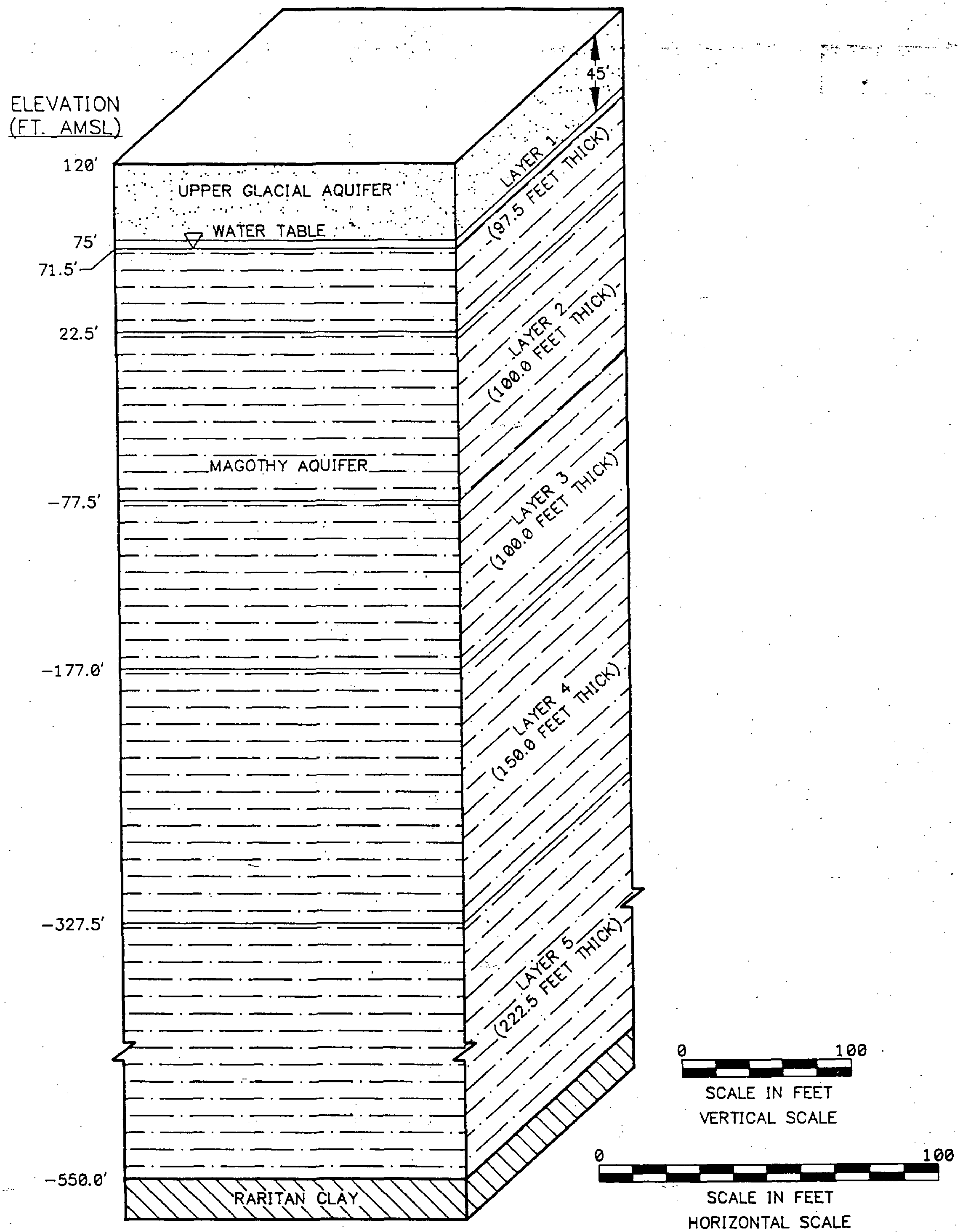
Because layers were defined based on monitoring well depths, the model layers are not directly related to lithologic units. Figure 4-2 illustrates the five model layers and their relationship to the aquifer units. Layer 1 contains the upper glacial aquifer, and the upper portion of the Magothy aquifer. Layers 2, 3, 4 and 5 are exclusively composed of the Magothy aquifer. The bottom of layer 5 is concurrent with the top of the Raritan Clay, which is a regional barrier to the downward movement of groundwater. Although some water may pass through the Raritan Clay to the underlying Lloyd aquifer, this amount of water was considered to be negligible, and the top Raritan Clay unit was assumed to be the bottom of the groundwater flow system.

Surface elevations (top of layer 1 elevation) were determined from U.S.G.S contour maps of the area. The surface contours were digitized and overlaid on to the model grid, and surface elevations for each node were approximated to the nearest 5.0 ft. Layer 1 ranges in thickness from 72.5 ft to 105 ft.. Layer 2 and 3 were defined to be 100 feet thick. Layer 4 was defined to be 150 ft thick, and layer 5 was defined to be 150 feet thick. The bottom of layer 5 was determined by digitizing the elevation of the top of the Raritan clay across the area from a literature source and overlaying the model grid, and approximating the elevation to the nearest 10.0 ft (Smolensky and Feldman, 1990).

4.3 GENERAL HYDROGEOLOGIC CONDITIONS IN THE MODEL AREA

Based on monthly rounds of water-level elevations taken from monitoring wells and groundwater flow direction data from literature sources, the normal groundwater flow (under non-pumping conditions) is generally towards the south (Isbister, 1966; Smolensky and Feldman, 1990). Under pumping conditions, the activity at Grumman production wells, recharge basins and BWD wells significantly alters the local groundwater flow directions.

Groundwater is derived from precipitation and infiltration from industrial and residential recharge basins. The ultimate discharge point for water in the groundwater system is the Atlantic Ocean. Discharge form the model area will occur at the southern border of the model, which is also designated as a constant head boundary. Evapotranspiration and runoff are accounted for in the values used for infiltration (recharge). Additionally, during pumping conditions the water pumped from the BWD wells was



MODFLOW LAYERS AT GRID BLOCK: 22, 30 BETHPAGE NWIRP

FIGURE 4-2

HALLIBURTON NUS
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considered to be removed from the system.

Based on literature sources and pumping tests conducted at the NWIRP, groundwater is considered to be unconfined (Isbister, 1966). The first laterally extensive layer which prevents the downward movement of groundwater is the Raritan Clay, which is approximately 600 feet below ground surface and is considered to be the regional flow barrier. The NWIRP occupies an area of recharge, and groundwater exhibits a downward flow direction.

4.4 INITIAL ESTIMATES OF HYDROGEOLOGIC PARAMETERS

4.4.1 Hydraulic Conductivity

Hydraulic conductivity values are specified in two directions: horizontal hydraulic conductivity (x- and y-direction) and vertical hydraulic conductivity (z-direction). Initial values for horizontal and vertical hydraulic conductivities were determined from the two pumping tests which were performed in the NWIRP area and from literature sources (Isbister, 1966; Smolensky and Feldman, 1990; Mc Clymonds and Franke, 1973). Pump test results are fully summarized in Appendix E.

In layer 1, the initial vertical hydraulic conductivity value was assumed to be one-tenth the horizontal conductivity for each node. For layers 2, 3 and 4 the ratio of vertical to horizontal conductivities decreased with depth. In layer 5 the initial vertical hydraulic conductivity values were assumed to be approximately one-fifth the horizontal conductivity values. Final values of hydraulic conductivity were determined during model calibration.

4.4.2 Storage

Initial storage values were derived from pumping test data and literature sources (Isbister, 1966). Final values were determined from model calibration. Storage values effect model solutions only during transient solutions.

4.4.3 Porosity

Initial values for porosity were determined from literature sources (Isbister, 1966; Fetter, 1988). For all nodes porosity was estimated at 0.20. Changes in the values of porosity does not effect groundwater flow directions or paths, although it does effect the rate at which groundwater moves through the aquifer.

4.4.4 Recharge

Recharge values were estimated from literature values, and from data from a climatic measuring station in Mineola, NY, approximately 10 miles from the NWIRP (Smolensky and Feldman, 1990; Feldman, Smolensky and Masterson, 1992). Average precipitation was 44.58 inches. It was assumed that 50% of precipitation was lost to runoff, evapotranspiration, or other sources while the remaining 50% recharged the groundwater system (Smolensky and Feldman, 1990). Recharge was added to the top layer only and was applied at the same rate for each node over the model grid.

4.5 BOUNDARY CONDITIONS

Boundary conditions are parameters which specify the constant head of constant flux at the boundaries and top surface of the modeled area. The types of boundary conditions used during these simulations include constant head boundaries, with specified heads during the simulation and specified flow boundaries, where the flux across a boundary is given. Water enters the model area at constant head boundaries along the north boarder of the modeling grid. Although actual water elevations at these points will fluctuate over time, it was assumed that fixed values could be assigned to these nodes for different months, due to the long-term nature of the steady-state simulations

4.5.1 Constant Head Boundaries

The boundary conditions applied to the northern and southern border of the model grid were designated as constant head boundaries. The value for constant head elevation for each node was initially determined from water-table elevation maps from literature sources (Smolensky and Feldman, 1990). Water elevations were digitized, and overlaid on to the modeling grid. Each node was assigned an constant head elevation to the nearest 0.10 ft. The final constant head elevations assigned to all layers were determined during model calibration.

4.5.2 Specified Flux Boundaries

The value of flux across the top face of each node in layer 1 was specified to simulate the infiltration of precipitation. Flux was constant at 0.0051 ft/d, which is equal to 24.34 inches of recharge per year or one half of the total average precipitation for the area (Smolensky and Feldman, 1990).

The east and west boundaries of the modeled area were specified as no flow boundaries in all five layers (constant flux of zero). This assumption was based on potentiometric surface maps of the area, which indicate groundwater flow in the area is generally parallel to these borders, with little or no flow across the boundaries.

4.5.3 Starting Head Values

For steady-state simulations, the starting head elevations for all layers were specified for each node in the grid. When performing steady-state simulations, the values of initial head were specified to be above the top elevation of the highest cell, at 145 ft. This initial water elevation was necessary to prevent cells from starting dry, which can add additional error to the simulation runs. Regardless of the starting head value used, the same solution result was obtained. For transient simulations, starting head values were specified for each grid-block and read from input files. Each time aquifer parameters were altered during the transient calibration, a steady-state simulation was run and the resulting values of head were used as the starting head for the transient simulation. For steady-state simulations, the starting head elevations for all layers were specified for each node in the grid. When performing steady-state simulations, the values of initial head were specified to be above the top elevation of the highest cell at 145 ft. This initial water elevation was necessary to prevent cells from starting dry, which can add additional error to the simulation runs. Regardless of the starting head value used, the same solution result was obtained.

5.0 COMPUTER CODE SELECTION

5.1 COMPUTER SOFTWARE

A groundwater flow model and a related particle tracking package were utilized in the modeling effort. The following subsections describe the general capabilities of these codes. These models were chosen because they can simulate the conceptual model constructed for the site. In addition, these models have been extensively verified and documented and have been used successfully at many different kinds of hazardous waste sites. There are many modeling packages which can be added to the basic flow model for in depth analysis and presentation of modeling results.

5.1.1 MODFLOW Program

The modular three-dimensional finite-difference groundwater flow model (known as MODFLOW) was developed by the U. S. Geological Survey to simulate groundwater flow in a variety of situations (Mc Donald and Harbaugh, 1988). This model can be used for two-dimensional or three-dimensional applications and can simulate the effects of wells, recharge, drains, and rivers, as well as a variety of boundary conditions.

MODFLOW has been used extensively at hazardous waste sites for simulation of groundwater flow and evaluation of remedial alternatives. This model can also be used in conjunction with other programs for modeling of contaminant transport and particle tracking. MODFLOW uses a block-centered grid for solving the finite-difference groundwater flow equations.

Input files for MODFLOW are generated using a separate software package, known as ModelCad. This package allows the user to generate graphical input of the modeling grid and aquifer parameters, which are then converted to input files for use in MODFLOW and the particle tracking software, MODPATH. The output from the MODFLOW model consists of heads generated for each model grid block for each layer, which can then be imported into the contouring program SURFER for graphical presentation.

5.1.2 MODPATH Program

MODPATH is a three-dimensional particle tracking code that was developed by the U. S. Geological Survey (Pollock, 1989). Although it utilizes heads calculated in MODFLOW to determine the direction of particle movement with time, MODPATH operates separately from MODFLOW. Two different particle tracking approaches can be used to illustrate the flow lines of a particle. In forward tracking mode, one or more particles are released from a suspected contaminant source, and the flow paths of these particles are calculated by MODPATH. The flow lines which represent particle movement through time can then be viewed in plan view or in cross-sectional view along model rows or columns. The second particle tracking mode is reverse particle tracking, where particles are released at a one or more grid blocks (generally at well nodes) and particles are tracked towards their point of origination, which indicates the capture zone of the wells.

The output generated by MODPATH consists of a listing of particle locations and travel times in a text file, which can be converted to graphical output using the program MODPATH-PLOT. MODPATH-PLOT can generate cross-sectional particle tracks along model rows and columns.

6.0 MODEL CALIBRATION

Following the construction of the conceptual model and the input of initial values for aquifer parameters, such as horizontal and vertical hydraulic conductivities, storage, recharge and constant head elevations, calibration of the flow model was initiated. Calibration included steady-state calibration of two separate pumping conditions at the Grumman site; low pumping conditions for Grumman production wells during February, 1992, and high pumping conditions for Grumman production wells during August 1992, and performing transient simulations of two pumping tests.

Model calibration refers to a demonstrating that the model is capable of producing water elevations which are comparable to water elevations measured on site. Steady-state calibration simulated two monthly pumping scenarios. Production well pumping rates and site wide water level data was used to check the simulated water elevations across the modeled area. Transient (stressed) conditions were calibrated by simulating two pumping tests performed on site. These pumping tests produced drawdowns within a small portion of the model grid, and transient calibration efforts were focused on this section of the model. Both transient and steady-state model calibration were performed by adjusting initial values of aquifer parameters and boundary conditions until an acceptable match of the modeled data was achieved when compared to observed measurements.

The calibration process was interactive between the steady-state and transient conditions. Any changes made to aquifer parameters during steady-state calibration were incorporated into the transient calibration model. Therefore, the final values of aquifer parameters determined during calibration represent a 'best-fit' for the measured steady-state and transient data sets.

6.1 CALIBRATION CRITERIA

The calibration criteria is the acceptable difference (expressed in feet) between the measured data and the modeled data for a given pumping situation. Calibration for the flow model was carried out until the difference between the heads predicted by the model and the measured heads were within the calibration criteria.

Generally, a groundwater flow model is to be considered calibrated when the difference between measured and modeled heads are less than one half the average fluctuation in the water table. In the area being modeled the water table had a natural fluctuation of approximately 4 ft, during 1991 and 1992, as shown in Table 6-1. Therefore, a general calibration criteria of 2.0 ft was established, and was used for the steady-state model calibration.

For the transient pump test simulations, a more rigorous calibration criteria of 1.0 ft was used for several reasons. Specifically, the pumping tests were performed in a small portion of the modeling grid, where numerous data points were present, node spacing is most dense, and precise measurements were made throughout the pumping tests. In addition, the flow of groundwater in the area around the NWIRP is of primary concern, as a potential source of contaminants (Site 1) is known to exist in these areas. For these reasons the 1.0 ft calibration criteria was used for transient simulations, and the modeled pumping tests were considered to be calibrated when model predictions of drawdowns were ± 1.0 ft when compared to measured drawdowns at each monitoring well.

As part of the MODFLOW model, a volumetric budget (or water balance) is calculated internally by the program and acts as a check on the total amount of water entering and leaving the flow system (Mc-Donald and Harbaugh, 1988). This water balance provides an indication of the overall acceptability of the solution, although does not indicate how accurately the model reflects the natural system. For example, a large water budget error can indicate problems with the conceptual model or hydraulic conductivities of the model. The water budget calculates how much water enters the system from precipitation, recharge basins, and constant head boundaries and compares this to the amount of water leaving the system due to well pumpage and constant head boundaries. Results are expressed in terms of percent error with ±0.50% error being considered to be the maximum allowable water balance error for all transient and steady-state calibration runs.

TABLE 6-1
MONITORING WELL WATER ELEVATIONS - 1991 AND 1992
PAGE 1 of 2

WELL	GRID LOCATION (R,C,L)	1991 OCT. 21	1991 NOV. 25	1991 DEC. 18	1992 JAN. 24	1992 FEB. 21	1992 MARCH 27	1992 APRIL 24	1992 MAY 29	1992 JUNE 26
GERAGHTY & MILLER WELLS										
GM-2S	2, 33, 1	76.30	76.45	76.24	75.75	75.16	74.47	74.04	72.90	72.74
GM-2I	6, 33, 2	75.85	75.44	75.38	74.97	74.09	73.50	73.10	71.86	71.62
GM-3S	4, 10 1	75.56	75.54	75.69	75.15	74.56	74.07	73.58	71.90	71.68
GM-3I	*6, 9, 2*	75.01	75.07	75.24	74.68	74.05	73.57	73.14	71.44	71.10
GM-4S	7, 9, 1	76.36	76.36		75.94	75.23	74.99	74.34	73.30	73.72
GM-4I	7, 9, 2	74.89	74.89		74.53	74.04	73.54	72.93	71.44	71.08
GM-5S	10, 10, 1	74.38	74.38		74.20	73.52	73.15	72.58	71.05	70.54
GM-5I	10, 10, 2	74.28	74.28		73.96	73.34	72.97	72.34	70.70	70.27
GM-6S	11, 21, 1	74.55	74.55	74.54	73.88	73.29	72.70	71.37	70.66	69.34
GM-6I	*11, 21, 2*	69.59	69.57	69.50	68.69	68.06	67.60	66.93	65.43	65.15
GM-7S	13, 27, 1	75.88	75.32	73.45	72.52	73.16	72.64	72.12	71.25	71.43
GM-7I	13, 27, 2	75.66	75.23	73.00	72.10	73.07	72.57	73.93	71.06	71.19
GM-7D	13, 27, 3	73.77	74.11	72.15	71.01	72.16	71.77	70.73	69.26	69.09
GM-8S	15, 37, 1	77.75	76.79	75.14	74.30	73.77	73.20	72.76	72.99	74.19
GM-8I	*15, 37, 2*	76.50	75.89	74.64	71.94	73.31	72.77	72.21	72.00	72.71
GM-9S	13, 9, 1	73.63	73.63		73.31	72.70	72.35	71.76	70.30	69.72
GM-9I	13, 9, 2	73.60	73.60		73.26	72.70	72.35	71.72	70.26	69.63
GM-10S	20, 7, 1	72.82	72.82	72.49	72.22	71.83	71.40	70.81	69.72	68.98
GM-10I	21, 6, 2	72.70	72.69	72.71	72.25	71.75	71.19	70.77	69.47	68.59
GM-12S	29, 15, 1	72.96	72.61	72.45	71.70	71.11	70.62	70.15	69.22	68.96
GM-12I	29, 15, 2	72.58	72.30	72.16	71.33	70.82	70.37	69.82	68.81	68.43
GM-13S	31, 23, 1	73.10	72.47	72.67	71.06	70.55	69.99	69.62	68.99	69.28
GM13I	32, 23, 2	73.21	72.52	71.90	71.47	71.10	70.39	70.04	69.13	69.54
GM-13D	34, 22, 3	71.04	70.66	68.95	68.01	69.01	68.51	67.97	67.22	67.16
GM-14S	32, 28, 1	71.25	70.51	70.09	69.32	69.20	68.71	68.21	67.82	68.03
GM-14I	36, 25, 2	71.63	70.87	70.50	69.71	69.17	68.58	68.20	67.71	68.00
GM-15S	41, 38, 1	69.11	68.34	67.91	67.29	73.85	73.34	72.87	72.39	72.72
GM-15I	48, 40, 2	67.45	66.65	67.14	66.45	66.04	65.44	65.12	64.58	64.92
GM-16S	36, 16, 1	71.41	70.67	69.97	68.53	69.79	69.05	68.85	68.45	68.58
GM-16I	36, 16, 2	71.31	70.59	69.47	69.15	69.75	69.02	68.81	68.38	68.49
GM-17S	38, 9, 1	72.97	71.76	71.00	72.49	71.22	69.46	71.29	71.49	72.89
GM-18S	45, 11, 1	69.57	68.14	68.28	67.48	66.73	65.98	65.75	65.78	66.42
GM-18I	44, 11, 2	69.86	68.49	68.74	67.92	67.74	66.94	66.71	66.83	67.47
GM-19S	48, 33, 1	68.63	67.34	67.57	66.81	66.41	65.78	65.43	65.33	66.17
GM-19I	48, 33, 2	68.53	67.29	67.64	66.98	66.46	65.84	65.50	65.35	66.12
GM-20S	51, 16, 1	69.96	67.16	67.00	66.19	65.33	64.74	64.30	65.40	67.01
GM-20I	51, 16, 2	68.92	66.62	66.61	65.98	65.54	64.83	64.50	65.28	66.42
GM-20D	51, 16, 3	67.67	65.91	65.76	64.95	64.68	61.43	63.66	63.92	64.68
GM-21S	51, 23, 1	68.35	66.11	66.01	65.31	64.42	64.38	63.46	64.76	65.95
GM-21I	51, 23, 2	67.72	65.74	65.60	64.93	64.52	63.93	63.55	64.42	65.45
GM-22S	51, 30, 1	67.90	66.77	63.02	66.35	65.88	65.31	65.10	64.86	66.13
GM-22I	51, 30, 2	67.08	65.63	66.04	67.68	64.87	64.30	64.08	64.09	65.39
GM-23S	29, 8, 1	71.84	71.54	72.00	71.38	70.32	69.82	69.42	68.61	68.01
GM-23I	29, 8, 2	71.85	71.54	72.42	71.79	70.32	69.78	69.40	68.57	67.96
HALLIBURTON NUS WELLS										
HN-8D	*17, 37, 3*					70.95	70.35	69.85	69.49	70.15
HN-24S	13, 22, 1			72.99	72.35	71.69				69.55
HN-24I	13, 22, 2			72.62	71.73	71.18	70.78	70.06	68.78	68.34
HN-25S	16, 21, 1			73.84	73.07	72.40	71.87	71.38	70.53	70.56
HN-25I	16+17, 21+22, 2			73.83	73.02	72.23	71.91	70.99	70.15	70.14
HN-25D	16, 21, 3					71.21	71.11	69.29	67.80	67.54
HN-26S	18, 26, 1			75.38	74.51	74.23	73.63	72.83	73.55	74.33
HN-26I	19, 26, 2			74.86	74.24	73.28	72.61	72.05	71.79	72.26
HN-27S	22+23, 30, 1			75.38	74.64	74.21	73.68		74.34	75.94
HN-27I	22+23, 30, 2			74.88	74.09	73.61	72.98			
HN-28S	26+27, 29+30, 1			73.58	72.65	72.10	71.55	71.16	71.12	72.08
HN-28I	26+27, 29+30, 2			72.86	71.91	71.28	70.78	70.32	69.75	70.14
HN-29S	26+27, 26+27, 1			73.76	72.76	72.15	71.62	71.22	70.97	71.63
HN-29I	26+27, 26+27, 2			72.83	71.97	71.19	70.84	70.18	69.53	69.75
HN-29D	*26+27, 26+27, 3*					69.42	69.21	68.39	67.51	67.58
HN-30S	22, 36+37, 1			74.56	74.05	73.00	72.86	72.00	73.48	76.09
HN-30I	*22, 36+37, 2*			73.97	74.81	72.50	72.10	71.59	71.79	73.07

Note: Shading indicates water elevation not taken.
Italics indicate outlier well (not included in annual difference calculation).

TABLE 6-1
MONITORING WELL WATER ELEVATIONS - 1991 AND 1992
PAGE 2 of 2

WELL	GRID LOCATION (R,C,L)	1992 JULY 24	1992 AUG. 28	1992 SEPT. 25	HIGHEST WATER LEVEL	LOWEST WATER LEVEL	ANNUAL DIFFERENCE (ft)
GERAGHTY & MILLER WELLS							
GM-2S	2, 33, 1	72.10	72.39	71.73	76.45	71.73	4.72
GM-2I	6, 33, 2	71.05	71.28	70.84	75.85	70.84	5.01
GM-3S	4, 10 1	71.46	71.55	71.50	75.69	71.50	4.19
GM-3I	*6, 9, 2*	70.49	74.96	70.31	75.24	70.31	4.93
GM-4S	7, 9, 1	73.04	74.49	72.68	76.36	72.68	3.68
GM-4I	7, 9, 2	70.42	70.84	70.29	74.89	70.29	4.60
GM-5S	10, 10, 1	70.04	70.37	69.78	74.38	69.78	4.60
GM-5I	10, 10, 2	69.68	69.57	69.56	74.28	69.56	4.72
GM-6S	11, 21, 1	69.70	69.88	69.69	74.55	69.34	5.21
GM-6I	*11, 21, 2*	64.39	64.72	64.72	69.59	64.72	4.87
GM-7S	13, 27, 1	70.56	70.73	70.38	75.88	70.38	5.50
GM-7I	13, 27, 2	70.36	70.52	70.31	75.66	70.31	5.35
GM-7D	13, 27, 3	67.84	68.41	69.25	74.11	67.84	6.27
GM-8S	15, 37, 1	74.71	74.87	73.63	77.75	72.76	4.99
GM-8I	*15, 37, 2*	73.64	72.84	72.16	76.50	72.00	4.50
GM-9S	13, 9, 1	69.17	70.62	69.04	73.63	69.04	4.59
GM-9I	13, 9, 2	69.05	69.45	69.05	73.60	69.05	4.55
GM-10S	20, 7, 1	68.62	68.75	68.48	72.82	68.48	4.34
GM-10I	21, 6, 2	68.31	67.37	68.32	72.71	67.37	5.34
GM-12S	29, 15, 1	68.60	68.78	68.47	72.96	68.47	4.49
GM-12I	29, 15, 2	68.04	68.29	68.23	72.58	68.04	4.54
GM-13S	31, 23, 1	68.88	70.61	68.84	73.10	68.84	4.26
GM13I	32, 23, 2	68.97	69.55	68.98	73.21	68.98	4.23
GM-13D	34, 22, 3	66.67	67.05	67.06	71.04	67.05	3.99
GM-14S	32, 28, 1	67.59	68.51	67.75	71.25	67.75	3.50
GM-14I	36, 25, 2	67.60	66.04	67.67	71.63	66.04	5.59
GM-15S	41, 38, 1	72.25	72.72	72.46	73.85	67.29	6.56
GM-15I	48, 40, 2	64.46	64.99	64.54	67.45	64.46	2.99
GM-16S	36, 16, 1	68.27	68.54	68.14	71.41	68.14	3.27
GM-16I	36, 16, 2	68.20	68.44	68.08	71.31	68.08	3.23
GM-17S	38, 9, 1	73.42	72.29	71.21	73.42	69.46	3.96
GM-18S	45, 11, 1	65.64	66.23	65.85	69.57	65.85	3.72
GM-18I	44, 11, 2	66.47	67.22	66.84	69.86	66.83	3.03
GM-19S	48, 33, 1	65.63	66.24	65.79	68.63	65.33	3.30
GM-19I	48, 33, 2	65.56	66.24	65.73	68.53	65.35	3.18
GM-20S	51, 16, 1	66.78	67.41	66.61	69.96	64.30	5.66
GM-20I	51, 16, 2	66.13	66.46	66.10	68.92	64.50	4.42
GM-20D	51, 16, 3	64.33	64.90	64.54	67.67	61.43	6.24
GM-21S	51, 23, 1	65.79	66.50	66.15	68.35	63.46	4.89
GM-21I	51, 23, 2	65.24	65.82	65.25	67.72	63.55	4.17
GM-22S	51, 30, 1	65.73	66.23	66.19	67.90	63.02	4.88
GM-22I	51, 30, 2	64.59	65.15	64.67	67.08	64.08	3.00
GM-23S	29, 8, 1	67.98	67.84	67.68	71.84	67.68	4.16
GM-23I	29, 8, 2	67.90	67.78	67.69	71.85	67.69	4.16
HALLIBURTON NUS WELLS							
HN-8D	*17, 37, 3*	70.88	70.55	69.96	70.95	69.49	1.46
HN-24S	13, 22, 1	69.32	69.47	69.04	72.99	69.04	3.95
HN-24I	13, 22, 2	67.80	68.10	68.34	72.62	68.10	4.52
HN-25S	16, 21, 1	69.83	69.83	69.53	73.84	69.53	4.31
HN-25I	16+17, 21+22, 2	69.26	69.41	69.51	73.83	69.26	4.57
HN-25D	16, 21, 3	66.49	66.83	68.39	71.21	68.39	2.82
HN-26S	18, 26, 1	72.91			75.38	72.83	2.55
HN-26I	19, 26, 2	71.47	71.02	70.96	74.86	70.96	3.90
HN-27S	22+23, 30, 1	77.70	75.64	74.28	77.70	74.21	3.49
HN-27I	22+23, 30, 2				74.88	72.98	1.90
HN-28S	26+27, 29+30, 1	71.97	72.41	71.47	73.58	71.16	2.42
HN-28I	26+27, 29+30, 2	69.86	70.05	69.84	72.86	69.75	3.11
HN-29S	26+27, 26+27, 1	71.13	71.50	70.69	73.76	70.69	3.07
HN-29I	26+27, 26+27, 2	69.27	69.56	69.45	72.83	69.45	3.38
HN-29D	*26+27, 26+27, 3*	66.88	67.24	67.53	69.42	67.24	2.18
HN-30S	22, 36+37, 1	80.64	79.36	77.70	80.64	72.00	8.64
HN-30I	*22, 36+37, 2*	74.84	74.36	73.45	74.84	72.10	2.74

AVERAGE ANNUAL DIFFERENCE (FT) 4.13

6.2 STEADY STATE CALIBRATION

Calibration of steady-state conditions was performed to correlate modeled water elevations with measured data for 61 observation wells located in the NWIRP and throughout the Grumman site. Steady-state calibration included performing simulations of two different pumping scenarios, which correspond to the lowest and highest yearly production rates at the Grumman production wells: low pumping conditions during February 1992, and high pumping conditions during August 1992. For these pumping scenarios monthly pumping rate data was available for each production well on the Grumman site, and water levels were taken at the end of each month.

Due to seasonal precipitation fluctuations the constant head values assigned to the boundaries changed for the two months for which model calibrations were performed.

6.2.1 Steady-State Calibration Procedures

For each steady-state simulation the average pumping rates was determined for each Grumman production well from monthly production well totals. Initially, recharge basins were assumed to receive all water pumped by the production wells. The simulation output was compared against the measured data, aquifer parameters were changed until the modeled data were within the ±2.0 ft calibration criteria of measured results, and a best-fit was achieved across the modeled area. The final values of recharge basin recharge rates were determined during model calibration and were within 90% of the total water pumped from the production wells. Steady-state simulations were run until there was a change in head of less than .0001 ft during one iteration of the simulation.

6.2.2 Steady-State Calibration Results

Calibration results for the low pumping conditions during February 1992 are presented on Table 6-2. Calibration results for the high pumping conditions during August 1992 are presented on Table 6-3. Calibration results summarized on these tables indicate that 56 of 61 wells in low pumping simulations, and 55 of 61 wells in high pumping situations fall within the calibration criteria of ±2.0 ft. The wells which

TABLE 6-2
MODEL CALIBRATION RESULTS
LOW PUMPING CONDITIONS - FEBRUARY 21, 1992

WELL	GRID LOCATION (R,C,L)	FEB. 21, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
GM-2S	2, 33, 1	75.16	75.49	0.33
GM-2I	6, 33, 2	74.09	73.23	-0.86
GM-3S	4, 10 1	74.56	73.99	-0.57
GM-3I	6, 9, 2	74.05	73.70	-0.35
GM-4S	7, 9, 1	75.23	75.35	0.12
GM-4I	7, 9, 2	74.04	73.88	-0.16
GM-5S	10, 10, 1	73.52	72.89	-0.63
GM-5I	10, 10, 2	73.34	72.79	-0.55
GM-6S	11, 21, 1	73.29	72.29	-1.00
GM-6I (1)	*11, 21, 2*	*68.06*	*72.24*	*4.18*
GM-7S	13, 27, 1	73.16	72.59	-0.57
GM-7I	13, 27, 2	73.07	72.50	-0.57
GM-7D	13, 27, 3	72.16	72.30	0.14
GM-8S	15, 37, 1	73.77	74.71	0.94
GM-8I	15, 37, 2	73.31	74.15	0.84
GM-9S	13, 9, 1	72.70	72.55	-0.15
GM-9I	13, 9, 2	72.70	72.41	-0.29
GM-10S	20, 7, 1	71.83	71.81	-0.02
GM-10I	21, 6, 2	71.75	71.24	-0.51
GM-12S	29, 15, 1	71.11	70.68	-0.43
GM-12I	29, 15, 2	70.82	70.64	-0.18
GM-13S	31, 23, 1	70.55	70.50	-0.05
GM13I	32, 23, 2	71.10	70.18	-0.92
GM-13D	34, 22, 3	69.01	69.59	0.58
GM-14S	32, 28, 1	69.20	70.44	1.24
GM-14I	36, 25, 2	69.17	69.29	0.12
GM-15S	41, 38, 1	73.85	73.47	-0.38
GM-15I	48, 40, 2	66.04	66.57	0.53
GM-16S	36, 16, 1	69.79	69.30	-0.49
GM-16I	36, 16, 2	69.75	69.25	-0.50
GM-17S	38, 9, 1	71.22	70.46	-0.76
GM-18S	45, 11, 1	66.73	67.27	0.54
GM-18I	44, 11, 2	67.74	67.21	-0.53
GM-19S	48, 33, 1	66.41	66.69	0.28
GM-19I	48, 33, 2	66.46	66.61	0.15
GM-20S	51, 16, 1	65.33	65.70	0.37
GM-20I	51, 16, 2	65.54	65.55	0.01
GM-20D	51, 16, 3	64.68	65.36	0.68
GM-21S	51, 23, 1	64.42	65.88	1.46
GM-21I	51, 23, 2	64.52	65.67	1.15
GM-22S	51, 30, 1	65.88	65.71	-0.17
GM-22I	51, 30, 2	64.87	65.56	0.69
GM-23S	29, 8, 1	70.32	70.50	0.18
GM-23I	29, 8, 2	70.32	70.45	0.13

TABLE 6-2
MODEL CALIBRATION RESULTS
LOW PUMPING CONDITIONS - FEBRUARY 21, 1992

WELL	GRID LOCATION (R,C,L)	FEB. 21, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
HN-8D (2)	*17, 37, 3*	*70.95*	*73.79*	*2.84*
HN-24S	13, 22, 1	71.69	72.12	0.43
HN-24I	13, 22, 2	71.18	72.05	0.87
HN-25S	16, 21, 1	72.40	71.77	-0.63
HN-25I	16+17, 21+22, 2	72.23	71.69	-0.54
HN-25D	16, 21, 3	71.21	71.43	0.22
HN-26S	18, 26, 1	74.23	72.80	-1.43
HN-26I	19, 26, 2	73.28	72.54	-0.74
HN-27S	22+23, 30, 1	74.21	74.38	0.17
HN-27I	22+23, 30, 2	73.61	73.68	0.07
HN-28S	26+27, 29+30, 1	72.10	72.38	0.28
HN-28I	26+27, 29+30, 2	71.28	72.20	0.92
HN-29S	26+27, 26+27, 1	72.15	71.84	-0.31
HN-29I	26+27, 26+27, 2	71.19	71.72	0.53
HN-29D (2)	*26+27, 26+27, 3*	*69.42*	*71.48*	*2.06*
HN-30S (2)	*22, 36+37, 1*	*73.00*	*76.80*	*3.80*
HN-30I (2)	*22, 36+37, 2*	*72.50*	*74.82*	*2.32*

NOTE: Calibration Criteria +/- 2.0 ft.
(1) Monitoring well not included in calibration due to proximity to production well.
(2) Monitoring well not included in calibration due to proximity to recharge basin.

MEAN ERROR:	-0.01
ABSOLUTE RESIDUAL VALUE:	28.26
MODFLOW WATER BALANCE ERROR:	-0.05%

TABLE 6-3
MODEL CALIBRATION RESULTS
HIGH PUMPING CONDITIONS - AUGUST 28, 1992

WELL	GRID LOCATION (R,C,L)	AUG. 28, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
GM-2S	2, 33, 1	72.39	73.20	0.81
GM-2I	6, 33, 2	71.28	71.05	-0.23
GM-3S	4, 10 1	71.55	71.71	0.16
GM-3I (2)	*6, 9, 2*	*74.96*	*71.60*	*-3.36*
GM-4S	7, 9, 1	74.49	74.38	-0.11
GM-4I	7, 9, 2	70.84	71.92	1.08
GM-5S	10, 10, 1	70.37	70.13	-0.24
GM-5I	10, 10, 2	69.57	70.00	0.43
GM-6S	11, 21, 1	69.88	69.23	-0.65
GM-6I (1)	*11, 21, 2*	*64.72*	*69.15*	*4.43*
GM-7S	13, 27, 1	70.73	70.37	-0.36
GM-7I	13, 27, 2	70.52	70.15	-0.37
GM-7D	13, 27, 3	68.41	69.61	1.20
GM-8S	15, 37, 1	74.87	75.59	0.72
GM-8I (2)	*15, 37, 2*	*72.84*	*70.53*	*-2.31*
GM-9S	13, 9, 1	70.62	69.65	-0.97
GM-9I	13, 9, 2	69.45	69.46	0.01
GM-10S	20, 7, 1	68.75	69.30	0.55
GM-10I	21, 6, 2	67.37	68.01	0.64
GM-12S	29, 15, 1	68.78	68.00	-0.78
GM-12I	29, 15, 2	68.29	67.95	-0.34
GM-13S	31, 23, 1	70.61	68.79	-1.82
GM13I	32, 23, 2	69.55	68.34	-1.21
GM-13D	34, 22, 3	67.05	67.78	0.73
GM-14S	32, 28, 1	68.51	68.88	0.37
GM-14I	36, 25, 2	66.04	67.73	1.69
GM-15S	41, 38, 1	72.72	72.45	-0.27
GM-15I	48, 40, 2	64.99	65.77	0.78
GM-16S	36, 16, 1	68.54	67.67	-0.87
GM-16I	36, 16, 2	68.44	67.54	-0.90
GM-17S	38, 9, 1	72.29	71.70	-0.59
GM-18S	45, 11, 1	66.23	66.80	0.57
GM-18I	44, 11, 2	67.22	66.66	-0.56
GM-19S	48, 33, 1	66.24	66.43	0.19
GM-19I	48, 33, 2	66.24	66.26	0.02
GM-20S	51, 16, 1	67.41	66.65	-0.76
GM-20I	51, 16, 2	66.46	66.13	-0.33
GM-20D	51, 16, 3	64.90	65.44	0.54
GM-21S	51, 23, 1	66.50	67.48	0.98
GM-21I	51, 23, 2	65.82	66.64	0.82
GM-22S	51, 30, 1	66.23	66.46	0.23
GM-22I	51, 30, 2	65.15	65.93	0.78
GM-23S	29, 8, 1	67.84	67.01	-0.83
GM-23I	29, 8, 2	67.78	66.94	-0.84

TABLE 6-3
MODEL CALIBRATION RESULTS
HIGH PUMPING CONDITIONS - AUGUST 28, 1992

WELL	GRID LOCATION (R,C,L)	AUG. 28, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
HN-8D (2)	*17, 37, 3*	*70.55*	*73.95*	*3.40*
HN-24S	13, 22, 1	69.47	68.98	-0.49
HN-24I	13, 22, 2	68.10	68.84	0.74
HN-25S	16, 21, 1	69.83	68.41	-1.42
HN-25I	16+17, 21+22, 2	69.41	68.30	-1.11
HN-25D	16, 21, 3	66.83	67.43	0.60
HN-26S	18, 26, 1	Dry	--	--
HN-26I	19, 26, 2	71.02	71.59	0.57
HN-27S	22+23, 30, 1	75.64	75.71	0.07
HN-27I	22+23, 30, 2	Destroyed	--	--
HN-28S	26+27, 29+30, 1	72.41	71.75	-0.66
HN-28I	26+27, 29+30, 2	70.05	71.39	1.34
HN-29S	26+27, 26+27, 1	71.50	70.47	-1.03
HN-29I	26+27, 26+27, 2	69.56	70.24	0.68
HN-29D (2)	26+27, 26+27, 3	67.24	69.77	2.53
HN-30S	22, 36+37, 1	79.36	81.03	1.67
HN-30I (2)	*22, 36+37, 2*	*74.36*	*76.71*	2.35

NOTE: Calibration Criteria +/- 2.0 ft.
(1) Monitoring well not included in calibration due to proximity to production well.
(2) Monitoring well not included due to proximity to recharge basin.

MEAN ERROR:	0.02
ABSOLUTE RESIDUAL VALUE:	36.64
MODFLOW WATER BALANCE ERROR:	-0.04%

fall outside the calibration criteria are described below.

For both pumping conditions, wells which do not fall within the calibration criteria (referred to as outlier wells) are located in the vicinity of a production well, recharge basins, or exhibit unusual water elevations during some of the period for which water elevations were measured. Numerous production wells and recharge basins are active across the NWIRP and the Grumman site, and these activities can effect the local water-table significantly. The outlier wells are believed to be influenced by a some, near by external stress, such as a active industrial or residential recharge basin.

Wells HN-6I, GM-8I, HN-8D, HN-29D, HN-30S and HN-30I are in close proximity to active recharge basins and exhibit modeled water elevations which fall outside the calibration criteria of ± 2.0 ft. The location of these wells near production wells or recharge basins may account for the disparities in model values of water elevations. Model pumping and recharge rates for production wells and recharge basins were determined from monthly totals, and these averages may not be accurate over shorter time periods, such as one day. Water levels taken in the immediate vicinity of recharge basins represent 'snap-shot' pictures of water elevations, and will record a sudden change in water elevation in a near-by recharge basin, such as when the water level increases or decreases suddenly in the recharge basin due to a production wells turning on or off. Monthly average pumping rates used in the model cannot simulate these daily changes for wells near the recharge basins. However, for wells not immediately adjacent to a recharge basin, the monthly averages represent good approximations of steady-state conditions over a monthly interval, as evidenced by the effective calibration of the majority of the monitoring wells during low and high pumping conditions.

Well GM-6I is located in the immediate vicinity of Grumman production well 13, an active production wells during 1991 and 1992. GM-6I shows a consistently low measured value, which may indicate that pumping activity at PW-13 may be effecting the modeled vs. measured results in a similar fashion as described above for wells near recharge basins. Pumping at PW-13 may have decreased the measured values at this well, while the model inputs assumed a consistent pumping rate throughout the month.

Well HN-15S, which fell within the calibration criteria, exhibits unusual water elevations consistently through out the 1992 period during which water elevations were taken. Typically a shallow and intermediate well in the same area will exhibit a decrease in head of approximately 1.5 ft of head or less, between the two wells. Figure 6-1 illustrates a graph of water levels at well HN-15S and HN-15I. The normal relationship is seen in the October 1991 through January 1992 data for GM-15S and GM-15I. The sudden increase in the water elevation at GM-15S during February, which does not effect GM-15I, does not conform to the typical trend of water levels at the site. This sudden increase in water level at GM-15S may be the result of a recharge basin or other external stress becoming active during the month of February 1992 and continuing at least through September 1992. To account for this, a recharge basin was assumed to be active in the vicinity of GM-15S, running at 306 gpm during low and high pumping conditions. This recharge rate for this recharge basin was determined during calibration to produce a result similar to the increase in water levels seen in the measured data at GM-15S.

Wells GM-3S, GM-3I, GM-4S. GM-4I, GM-5S, GM-5I and GM-9S, GM-9I, which are in the vicinity of the Hooker-Ruco chemical facility, generally were within the calibration criteria, although they consistently exhibited low modeled vs. measured results throughout model calibration. Three large recharge basins are present on the Hooker-Ruco site. Recharge activity at these Hooker-Ruco basins would account for the low modeled values produced at these wells during calibration simulations, as recharge may have been added to these basins during the two months used for calibration. Therefore, during the calibration simulations water was added at these basins to simulate recharge activity. Recharge rates at the Hooker-Ruco basins was determined during model calibration. During low pumping conditions, 202 gpm was added to each basin, while during high pumping conditions an average of 838 gpm was added to each basin. Table 6-4 shows the pumping and recharge rates used during the February and August, 1992 calibration scenarios.

The difference between the measured heads and the modeled heads was calculated for each well, and are listed in Tables 6-2 and 6-3. This value indicates if the measured water elevation at a well is within the calibration criteria. In addition to this value, two other quantitative calculations were preformed for the calibration runs to determine how closely the modeled data fit the measured data.

The sum of the differences of modeled data and measured data (referred to as the mean error) indicates the amount of positive or negative model error for the calibration run. The mean error is calculated by

Figure 6-1
GM-15S Water Elevation 1991 and 1992

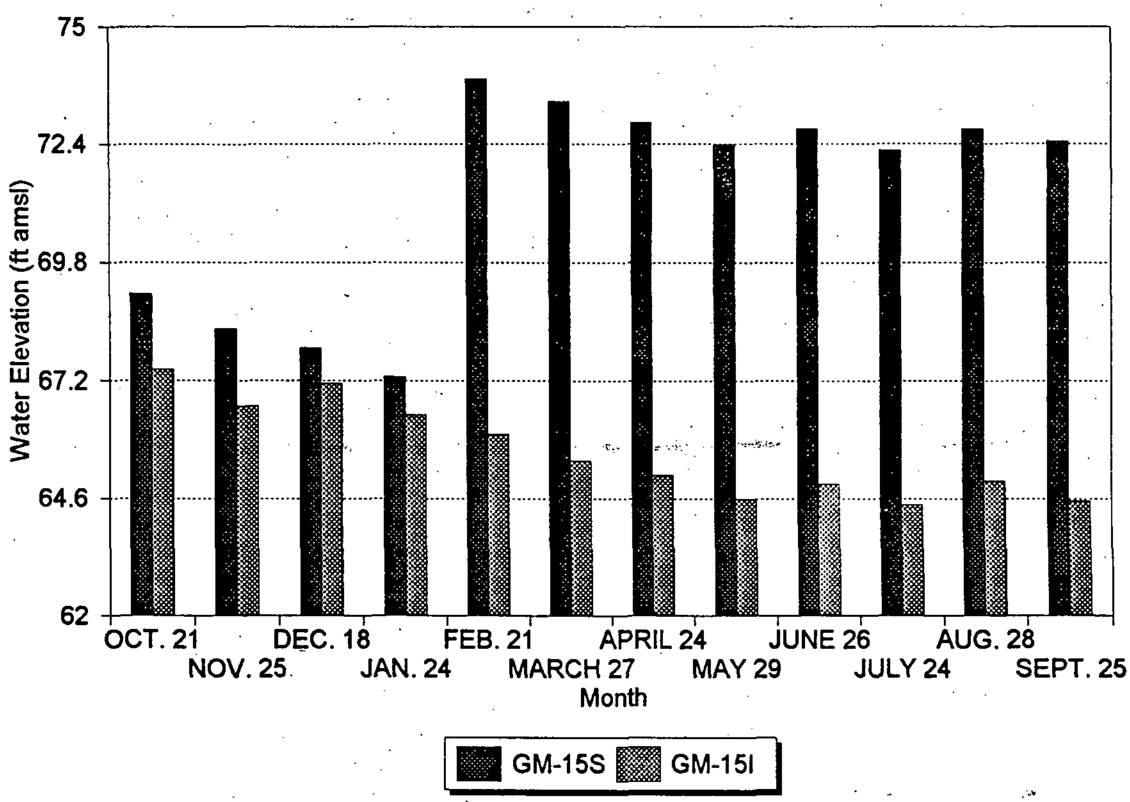


TABLE 6-4
PRODUCTION WELL PUMPING RATES FOR MODEL CALIBRATION SIMULATIONS

PRODUCTION WELL	LOCATION (ROW,COL.)	LAYER	% PUMPED FROM LAYER	FEBRUARY, 1992 (LOW PUMPING CONDITIONS) Actual Pumping rate (gpm)	FEBRUARY, 1992 (LOW PUMPING CONDITIONS) Model Pumping rate (gpm)	AUGUST, 1992 (HIGH PUMPING CONDITIONS) Actual Pumping rate (gpm)	AUGUST, 1992 (HIGH PUMPING CONDITIONS) Model Pumping rate (gpm)
SOUTH PRODUCTION WELLS							
PW-1	42, 10	5	100%	378	378	1,369	1,369
PW-2	34, 11	5	100%	0	0	0	0
PW-3	38, 9	5	100%	432	432	1	1
PW-4	39, 11	4	100%	0	0	0	0
PW-5	31, 9	4	100%	0	0	0	0
PW-6	27, 7	3	11%	0	0	122	122
		4	89%	0	0	987	987
SOUTH PRODUCTION WELL TOTALS:				810	810	2,479	2,479
SOUTH RECHARGE BASINS - OUTFALLS 005, 006 AND 007							
23 GRID BLOCKS (2	--	1.	100%	35	26	108	108
NORTH PRODUCTION WELLS							
PW-8	15, 13	4	16%	0	0	0	0
		5	84%	0	0	2	2
PW-9	16, 16	4	100%	305	305	1,155	1,155
PW-10	18, 19	4	100%	68	68	827	827
PW-11	19, 23	4	37%	220	220	260	260
		5	63%	375	375	443	443
PW-13	12, 18	5	100%	0	0	266	266
PW-14	21, 13	4	62%	0	0	0	0
		5	38%	0	0	0	0
PW-15	14, 26	5	100%	0	0	990	990
PW-16	9, 31	4	100%	862	862	986	986
NORTH PRODUCTION WELL TOTAL:				1,831	1,831	4,930	4,930
NORTH RECHARGE BASINS - OUTFALLS 004 AND 010							
24 GRID BLOCKS (2	--	1	100%	76	76	205	170
OTHER BASINS							
GM-15S BASIN	41, 38	1	100%	-	306	-	306
HOOKER-RUCO BASINS AVERAGE		1	100%	-	202	-	838

(1) MONTHLY PUMPING RATE FROM GRUMMAN AEROSPACE DATA.
(2) CALCULATIONS ARE TOTALS FOR EACH BASIN GRID BLOCK.

the following formula:

$$ME = \frac{1}{n}\sum_{i=1}^{n} [h_m - h_s]i$$

where ME is the mean error, hm is the measured head, hs is the simulated head, and n is the number of calibration values used. A zero value of mean error indicates equal amounts of positive and negative model error. Final calibration results for low pumping conditions have a mean error of -0.01 ft for low pumping conditions and 0.02 ft for high pumping conditions. Figures 6-2 and 6-3 graphically illustrates the amount of model error for the February and August 1992 simulations at each monitoring well. Because outlier wells may have been biased by recharge basin activity or production well activity, these wells were not included in the mean error values for these calibration scenarios. Figures 6-4 and 6-5 illustrate the amount of model error present at each monitoring well for the February and August, 1992 simulations for all wells, excluding the outlier wells. The mean error was minimized during model calibration. A small value of mean error alone does not indicate a good calibration, as both positive and negative mean errors are incorporated and may cancel out. For this reason, an additional measure of model accuracy was calculated.

The absolute residual value is the sum of the absolute values of the differences between measured and modeled data for each monitoring well, and is calculated using the formula:

$$AR = \frac{1}{n}\sum_{i=1}^{n} \mid [h_m - h_s]i \mid$$

where AR is the absolute residual value, hm is the measured head, hs is the simulated head, and n is the number of calibration values used. A low absolute residual value indicates a good match between measured and modeled data. The absolute residual value for low pumping and high pumping conditions was minimized during calibration. As noted in Tables 6-2 and 6-3, for low pumping conditions the absolute residual value was 28.26 ft, and for high pumping conditions absolute residual value was 36.64 ft. The outlier wells that fall outside the calibration criteria were not included in the calculation of mean error or absolute residual error because these wells were interpreted to be influenced by active recharge basins and production wells. In addition to the statistical checks made on calibration solutions noted above, the water balance of each calibration run was checked.

Figure 6-2
Model vs. Measured Values - Feb. 1992

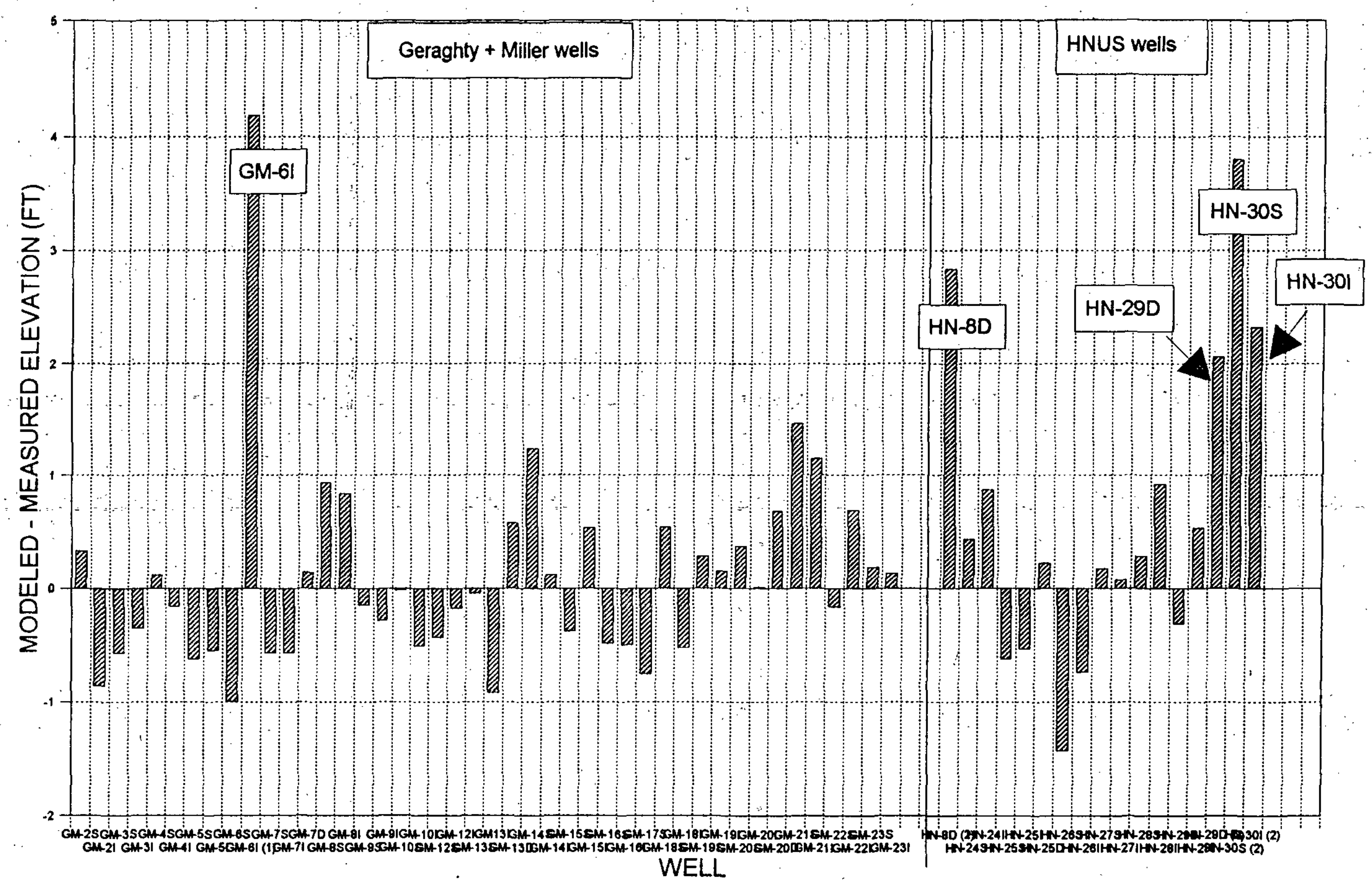


Figure 6-3
Model vs. Measured Values - Aug. 1992

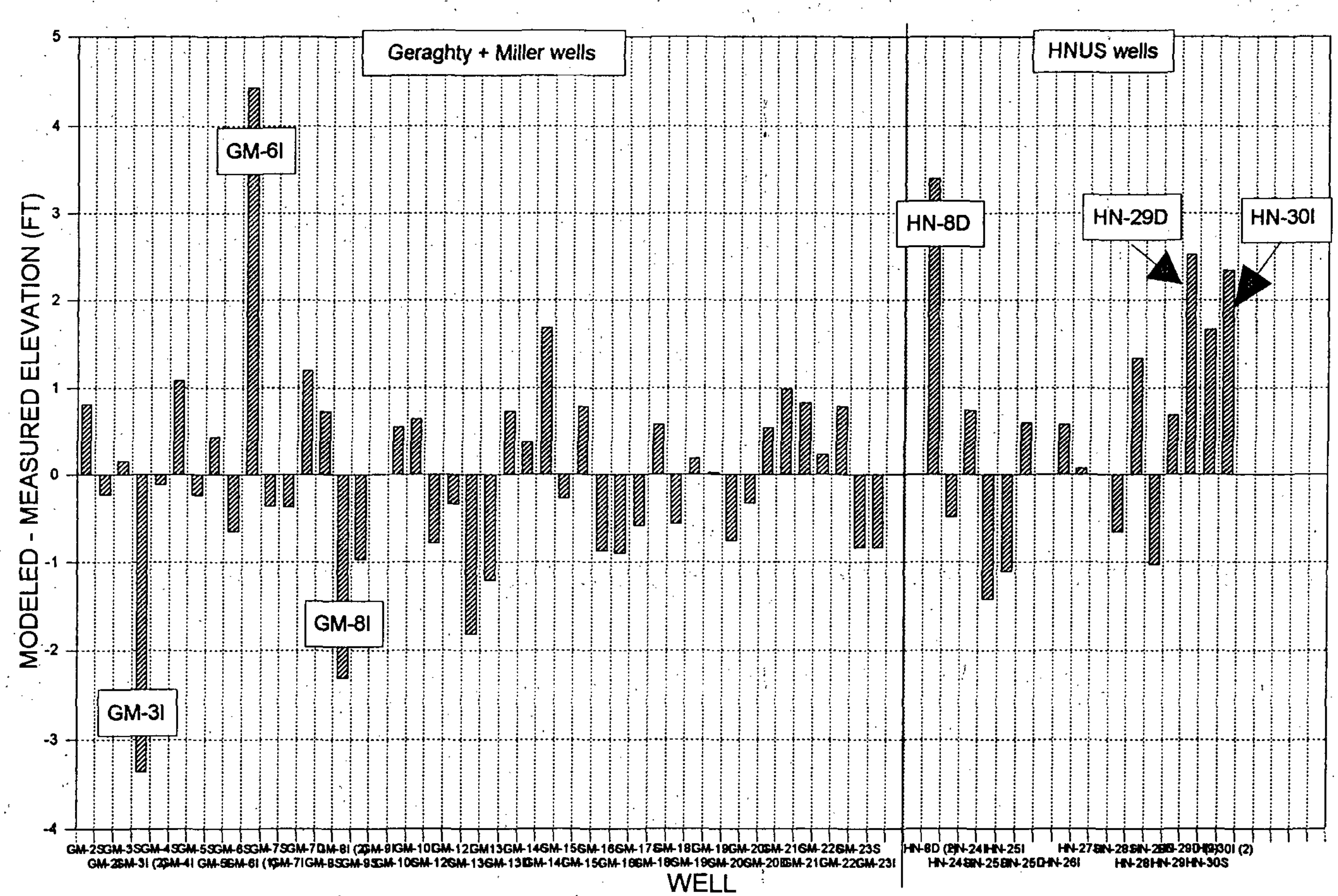


Figure 6-4
Model vs. Measured Values - Feb. 1992

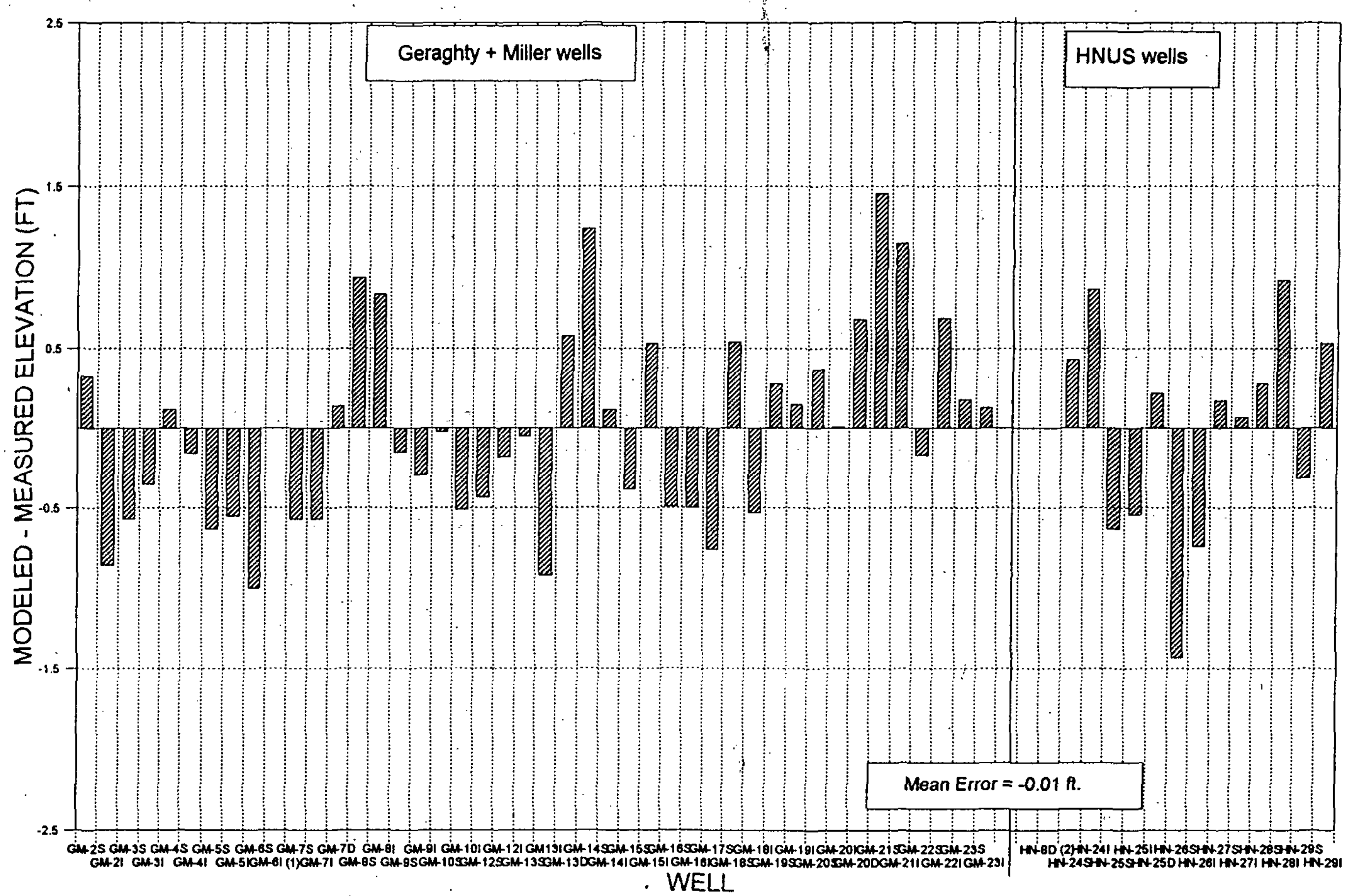
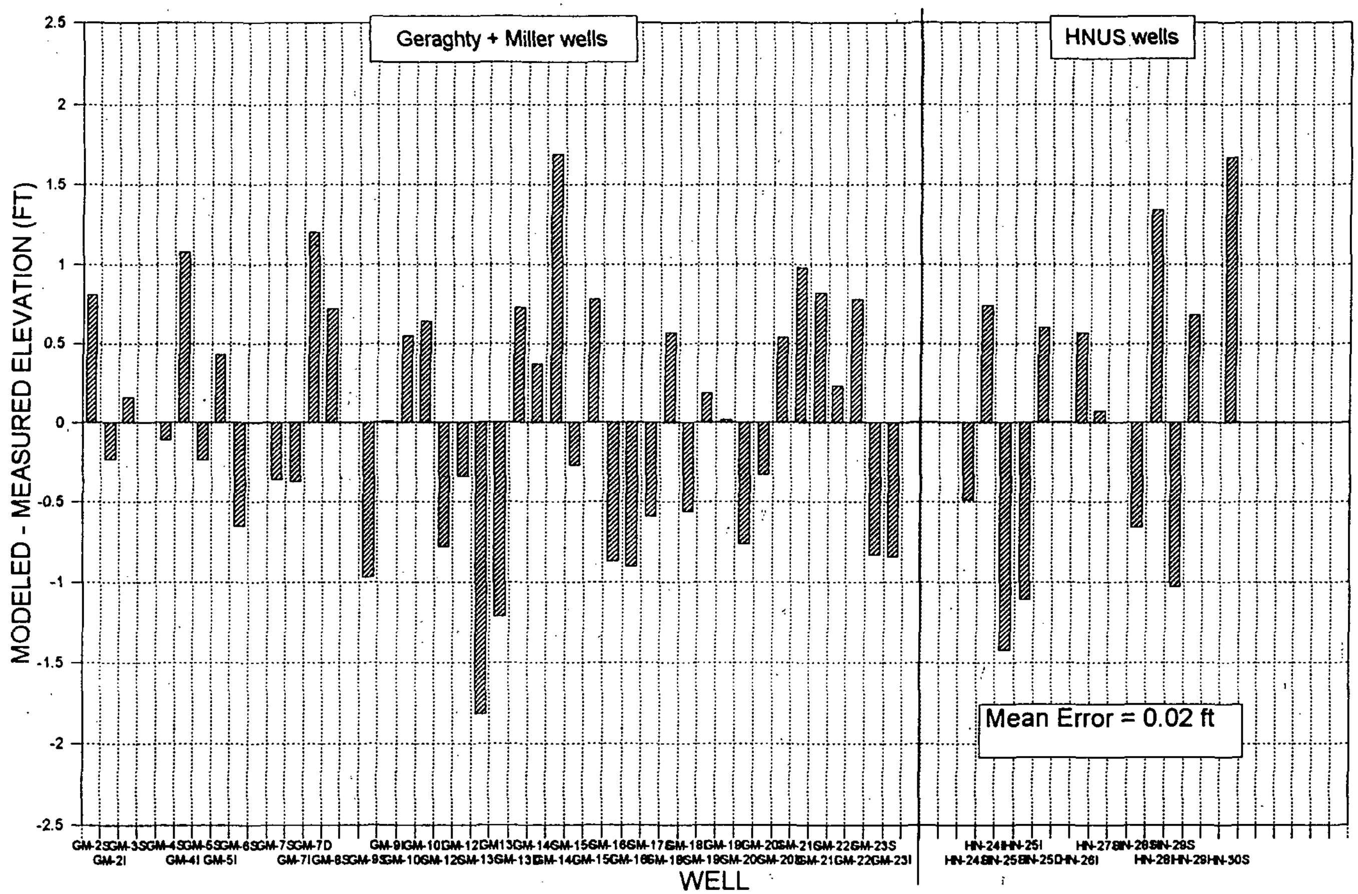


Figure 6-5
Model vs. Measured Values - Aug. 1992



All calibration runs fell below the ± 0.50 % water balance error criteria.

Qualitative water elevations are presented in the water-table maps which compare measurements of modeled and measured data. Figure 6-6 compares the February 1992 measured and modeled (low pumping) water-table map. Figure 6-7 compares the August measured and modeled (high pumping) water-table map.

6.3 TRANSIENT CALIBRATION

To calibrate the flow model for transient conditions, during which a stress is applied to the aquifer, two pumping tests which were conducted at the NWIRP, were simulated. The drawdowns produced in monitoring wells during the pumping tests were recorded, and this data was compared to model generated drawdowns. During pump test #1, the intermediate well HN-27I2 was pumping at a rate of 480 gpm for 2.8 days, while during pump test #2, the deep production well PW-11 was pumping at 890 gpm for 2.9 days. A complete discussion of the results for two pumping tests is provided in AppendixE.

6.3.1 Transient Calibration Procedures

Transient calibration began by performing modeling runs for the two pumping tests using the aquifer parameters determined during steady-state calibration. Subsequently, aquifer parameters, such as vertical and horizontal hydraulic conductivities, and storage were changed to achieved a best-fit between modeled and measured results for both pumping tests. For each pumping test simulation, all water pumped from the aquifer by the pumping well was assumed to be returned to the Grumman recharge basins via outfall 010, and no additional water from other site activities was contributed to the recharge basins. BWD wells were assumed to be distant enough from the pumping test activities to preclude any effect on the observed drawdowns, and therefore, the BWD wells were not active during the simulations.

6.3.2 Transient Calibration Results

Table 6-5 presents a summary of the calibration results for the two pumping test simulations. Time-drawdown graphs comparing the modeled drawdowns and recovery results for the final MODFLOW model to the measured data for pump test #1 are illustrated in Figures 6-8 through 6-19. The final

TABLE 6-5
SUMMARY OF CALIBRATION RESULTS
PUMP TEST #1 AND PUMP TEST #2

Well	Layer	Location (Row)	Location (Column)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Difference (ft) (1)
PUMP TEST #1						
HN-27S2	1	23	30	1.31	1.18	-0.13
HN-27S3		24	30	1.01	0.95	-0.06
HN-26I1	2	19	26	0.26	0.22	-0.04
HN-27I1		22	30	3.51	3.57	0.06
HN-27I2		23	30	5.05	5.13	0.08
HN-28I		26 27	29+30 29+30	0.59	0.51	-0.08
PUMP TEST #2						
HN-25S	1	21	16	0.08	0.29	0.21
HN-27S2		23	30	0.11	-0.84	-0.95
HN-25I	2	16 17	21+22 21+22	0.08	0.43	0.35
HN-26I1		19	26	0.04	0.15	0.11
HN-27I2		23	30	0.12	-0.65	-0.77
HN-28I		26 27	29+30 29+30	0.17	-0.26	-0.43
HN-29I		26 27	26+27 26+27	0.21	-0.02	-0.23
HN-25D	3	16	21	0.17	0.57	0.4
NH-29D		26 27	26+27 26+27	0.27	0.08	-0.19
PW-10	5	17 18	19+20 19+20	< 0.5	0.69	0.19
PW-11		19	23	1.03	1.86	0.83

NOTE: CALIBRATION CRITERIA FOR PUMP TEST SIMULATIONS = +/- 1.0 FT.
(1) DIFFERENCE = MODELED - MEASURED

Figure 6-8

HN-27S2 Drawdown for Pump Test #1

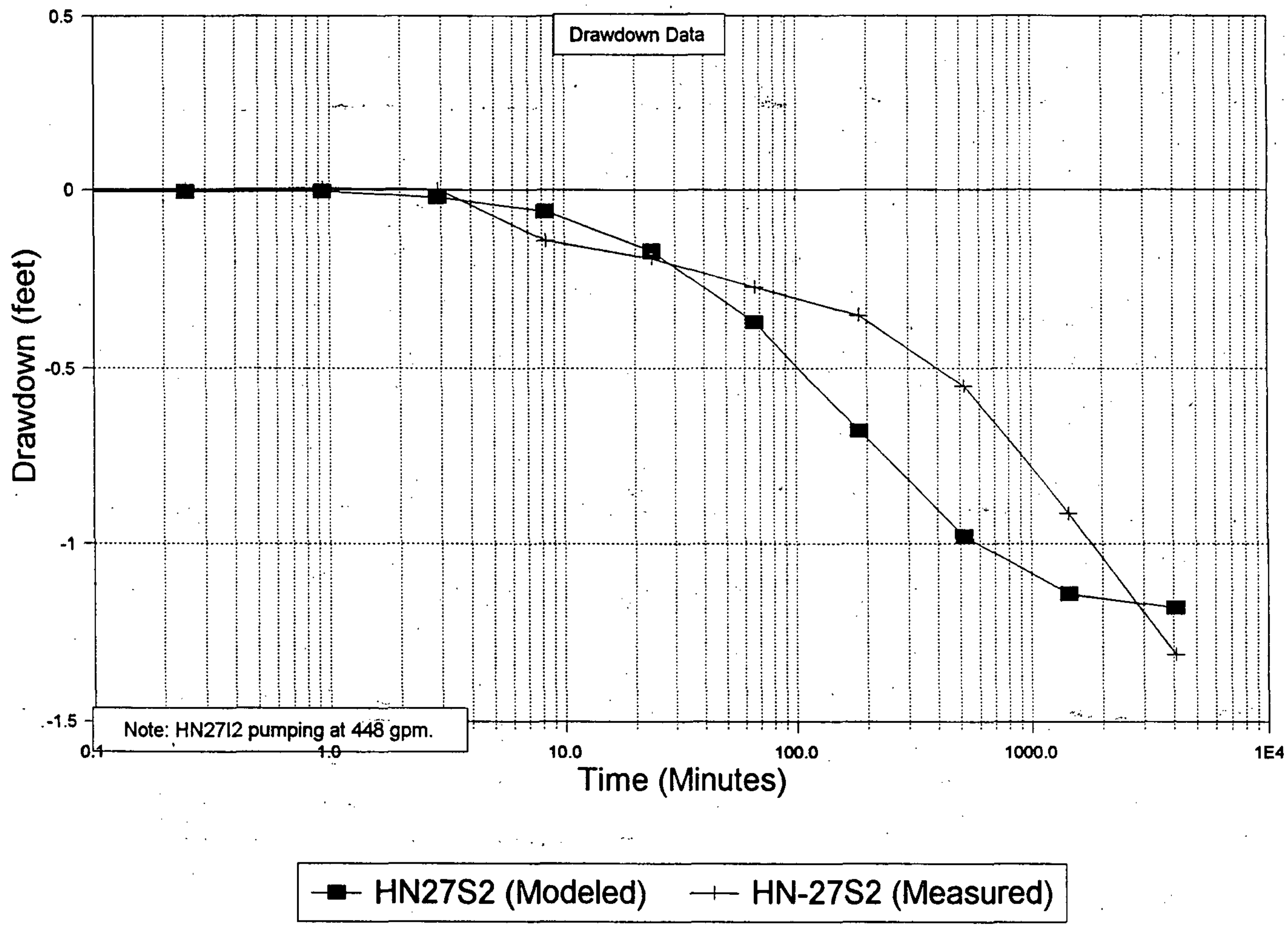


Figure 6-9

HN-27S3 Drawdown for Pump Test #1

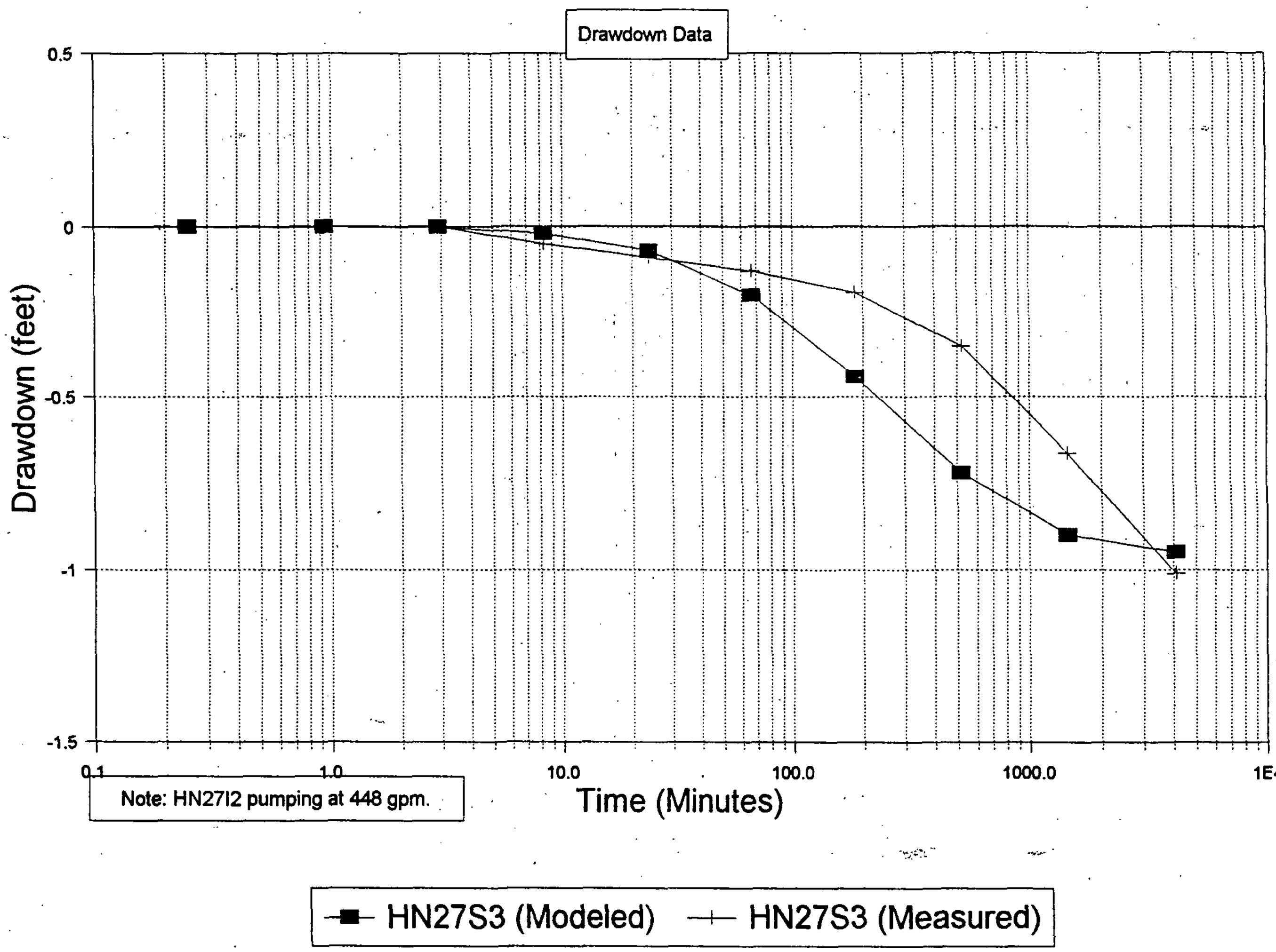


Figure 6-10

HN26I Drawdown for Pump Test #1

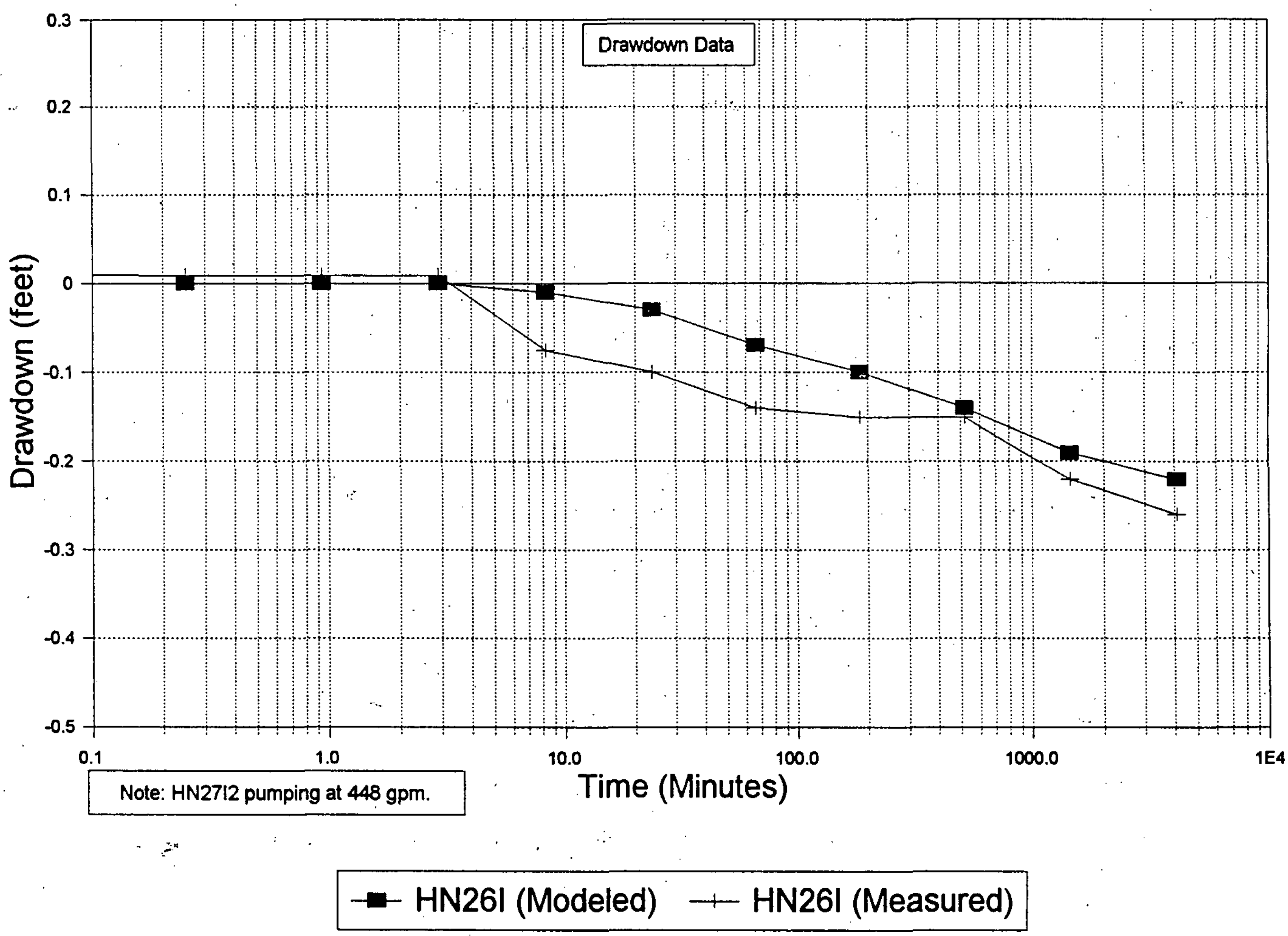


Figure 6-11
HN27I1 Drawdown for Pump Test #1

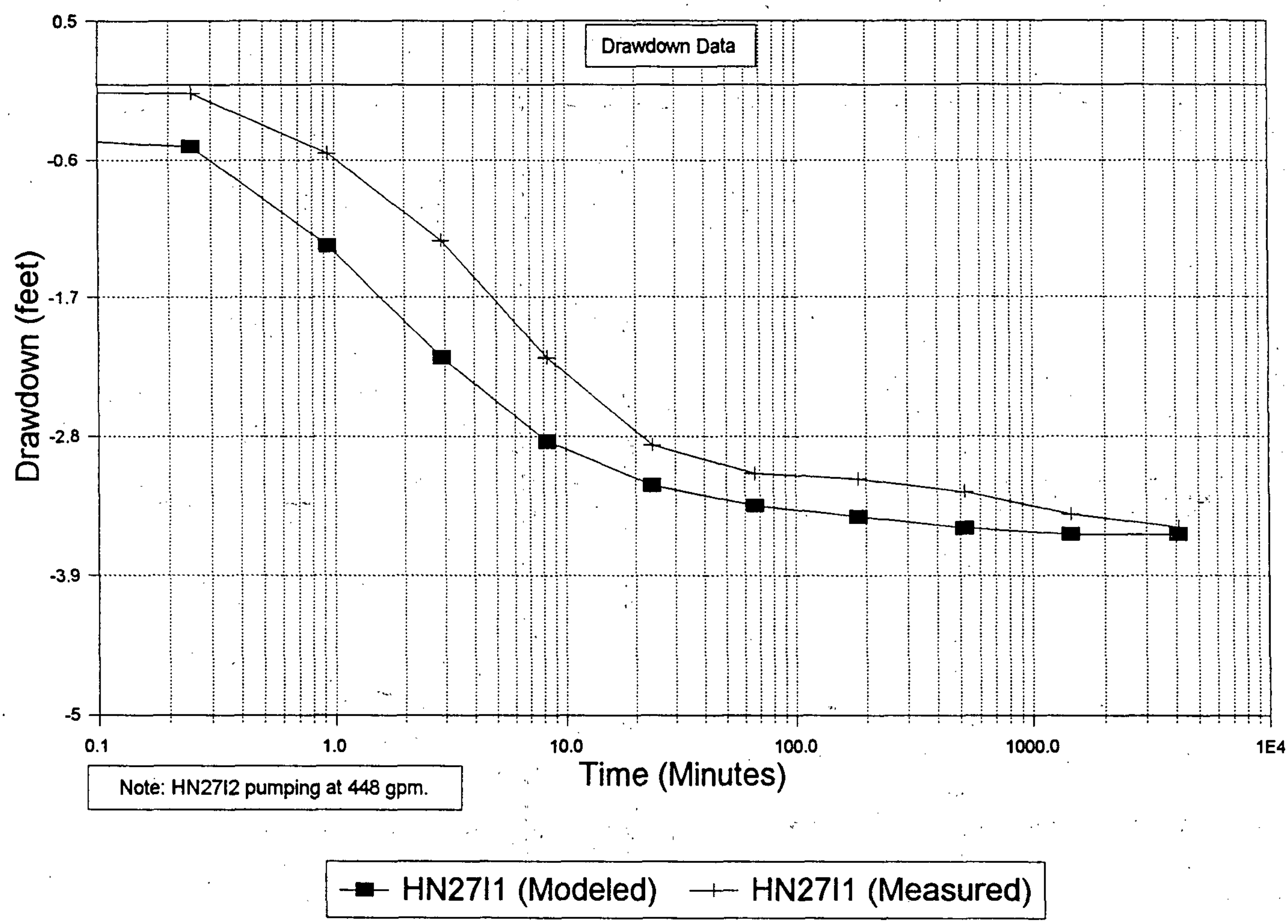


Figure 6-12
HN27I2 Drawdown for Pump Test #1

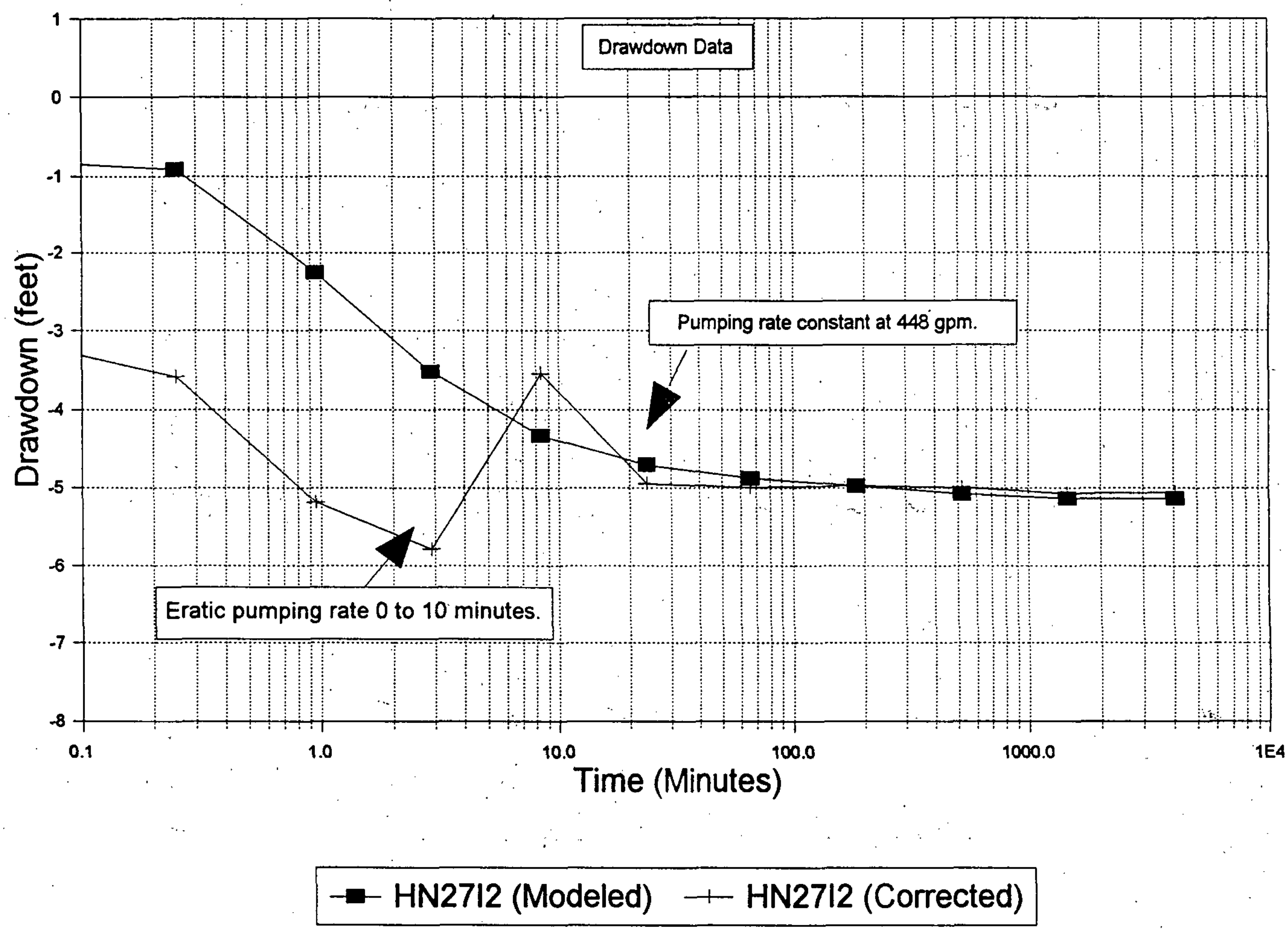


Figure 6-13
HN28I Drawdown for Pump Test #1

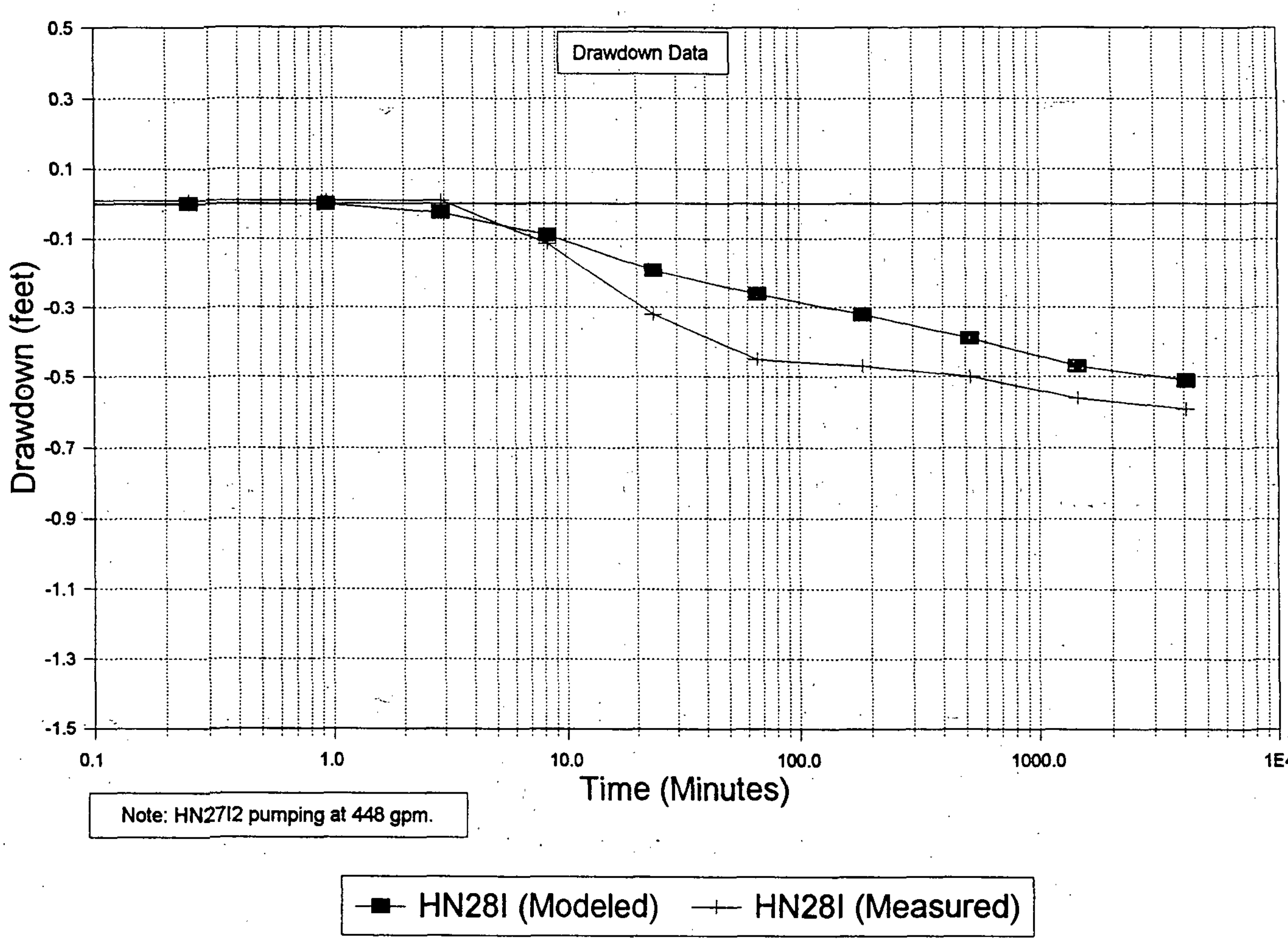


Figure 6-14

HN-27S2 Recovery for Pump Test #1

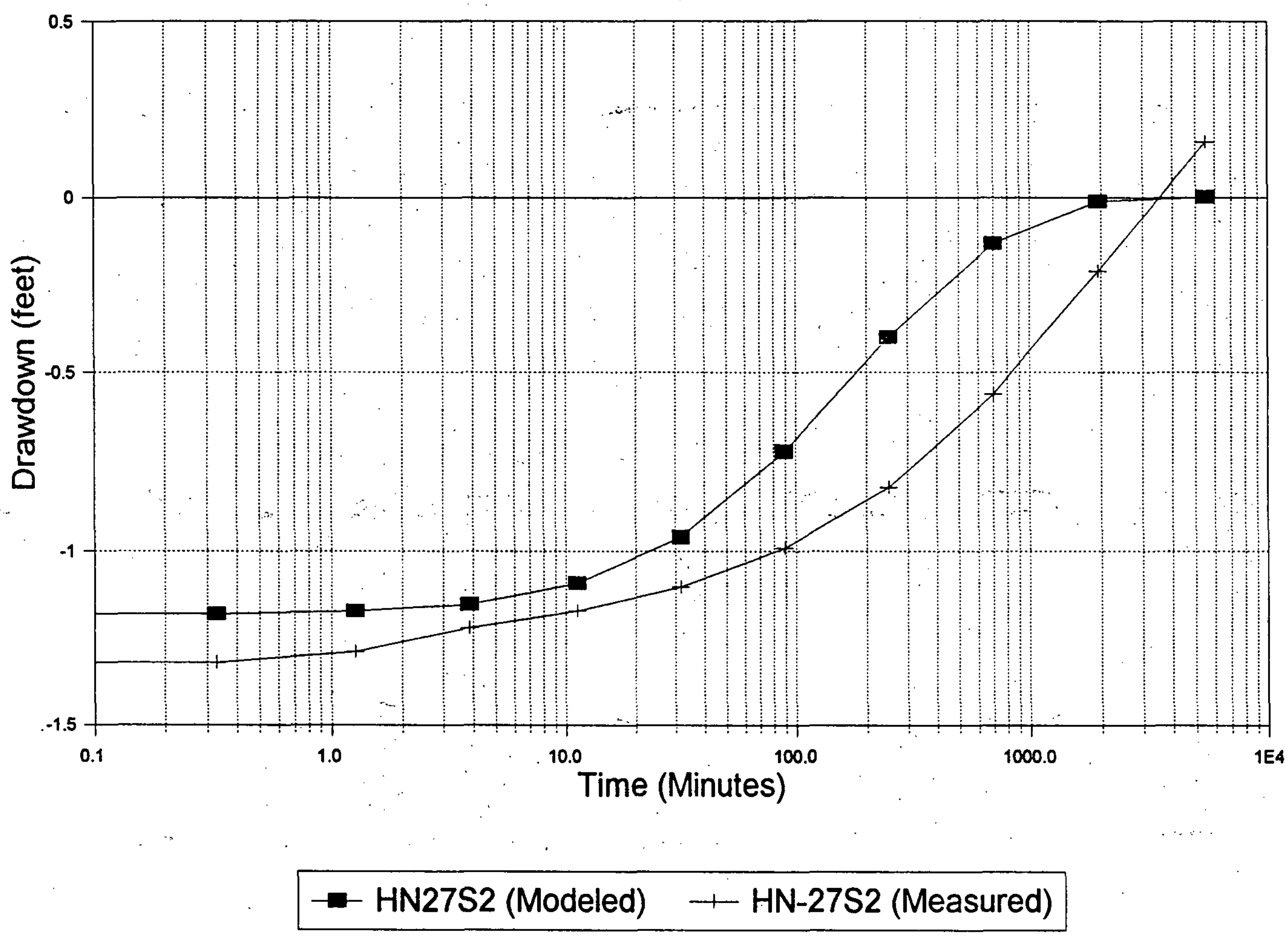


Figure 6-15
HN-27S3 Recovery for Pump Test #1

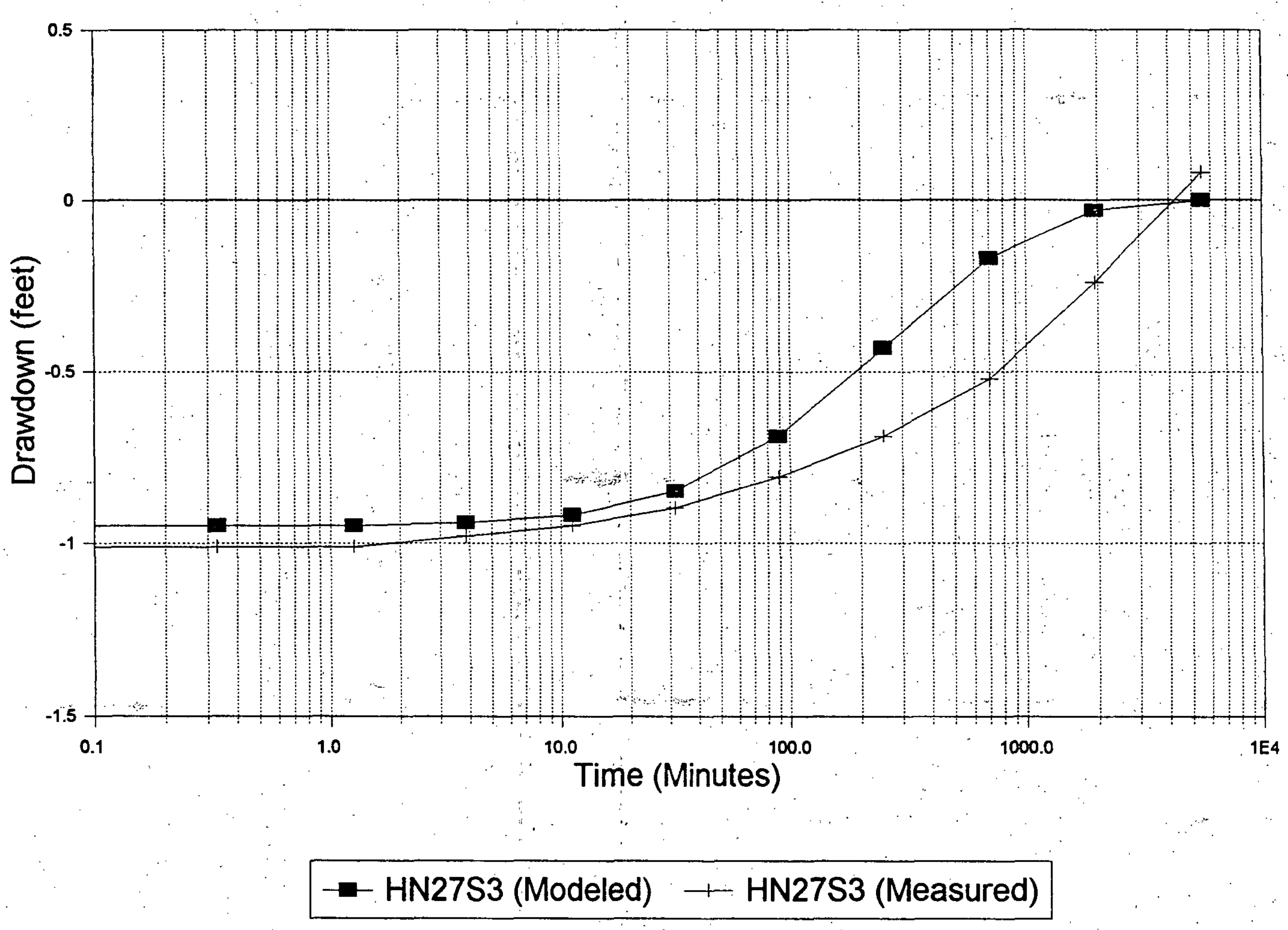


Figure 6-16
HN26I Recovery for Pump Test #1

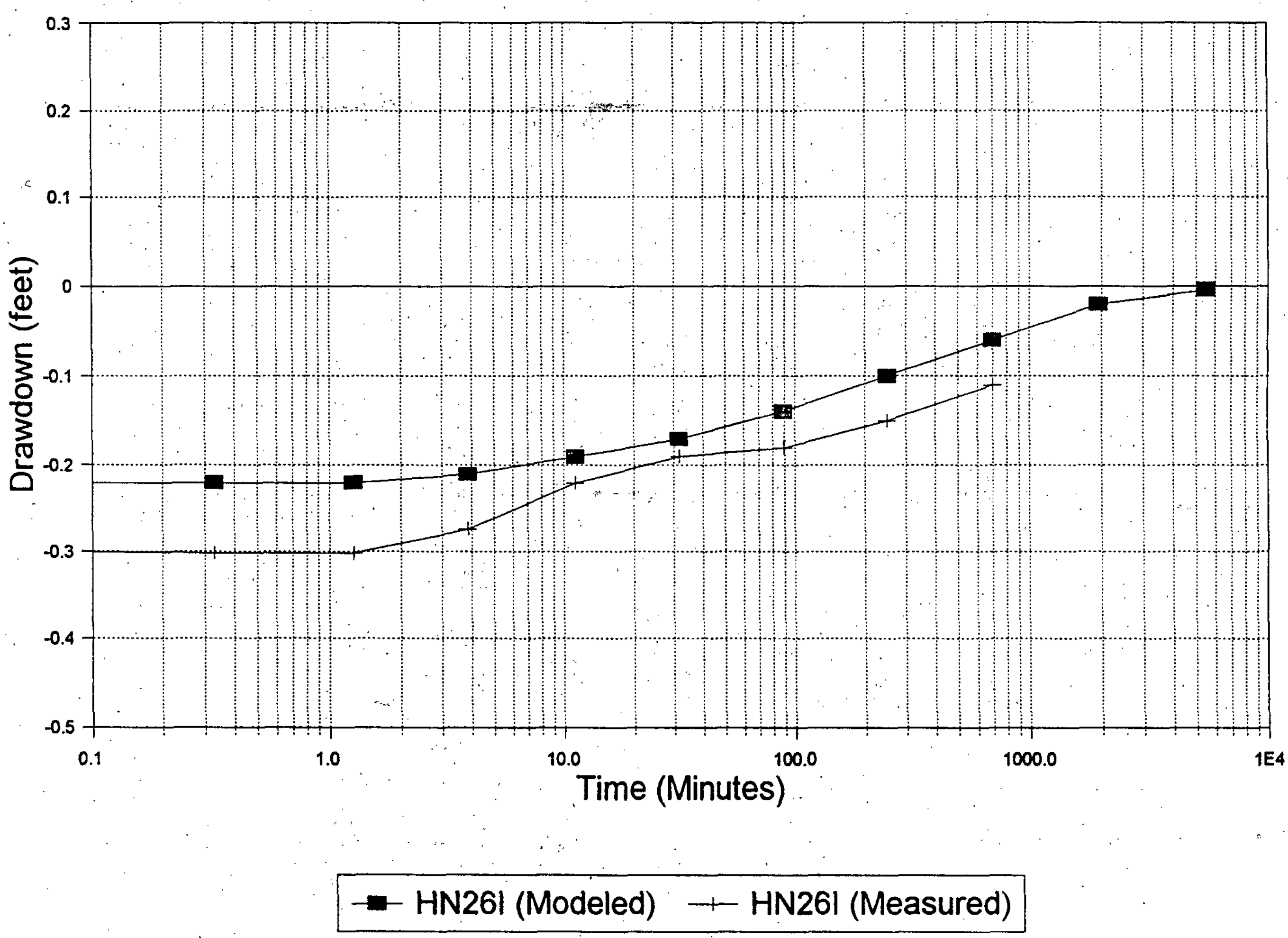


Figure 6-17

HN27I1 Recovery for Pump Test #1

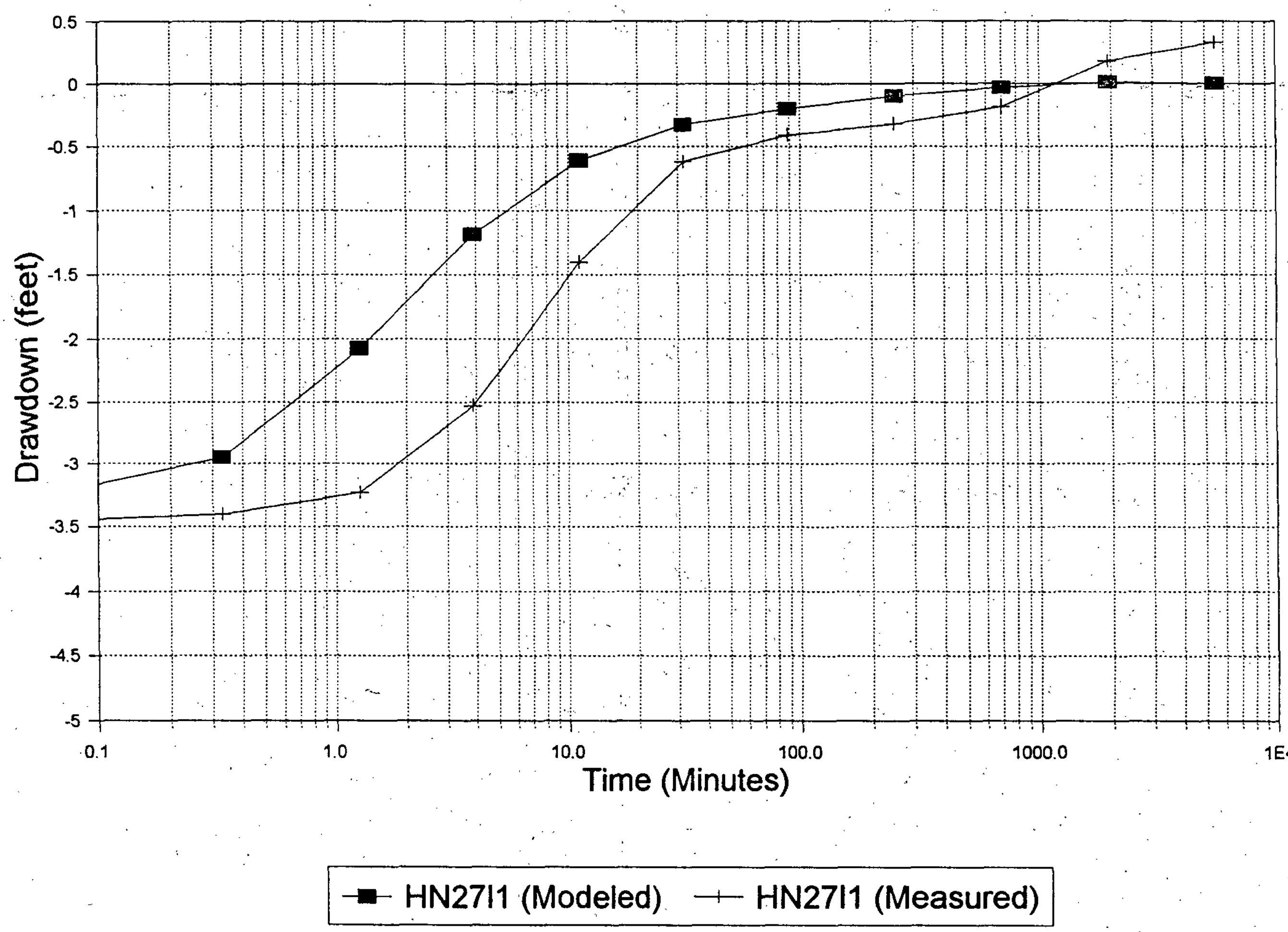


Figure 6-18

HN27I2 Recovery for Pump Test #1

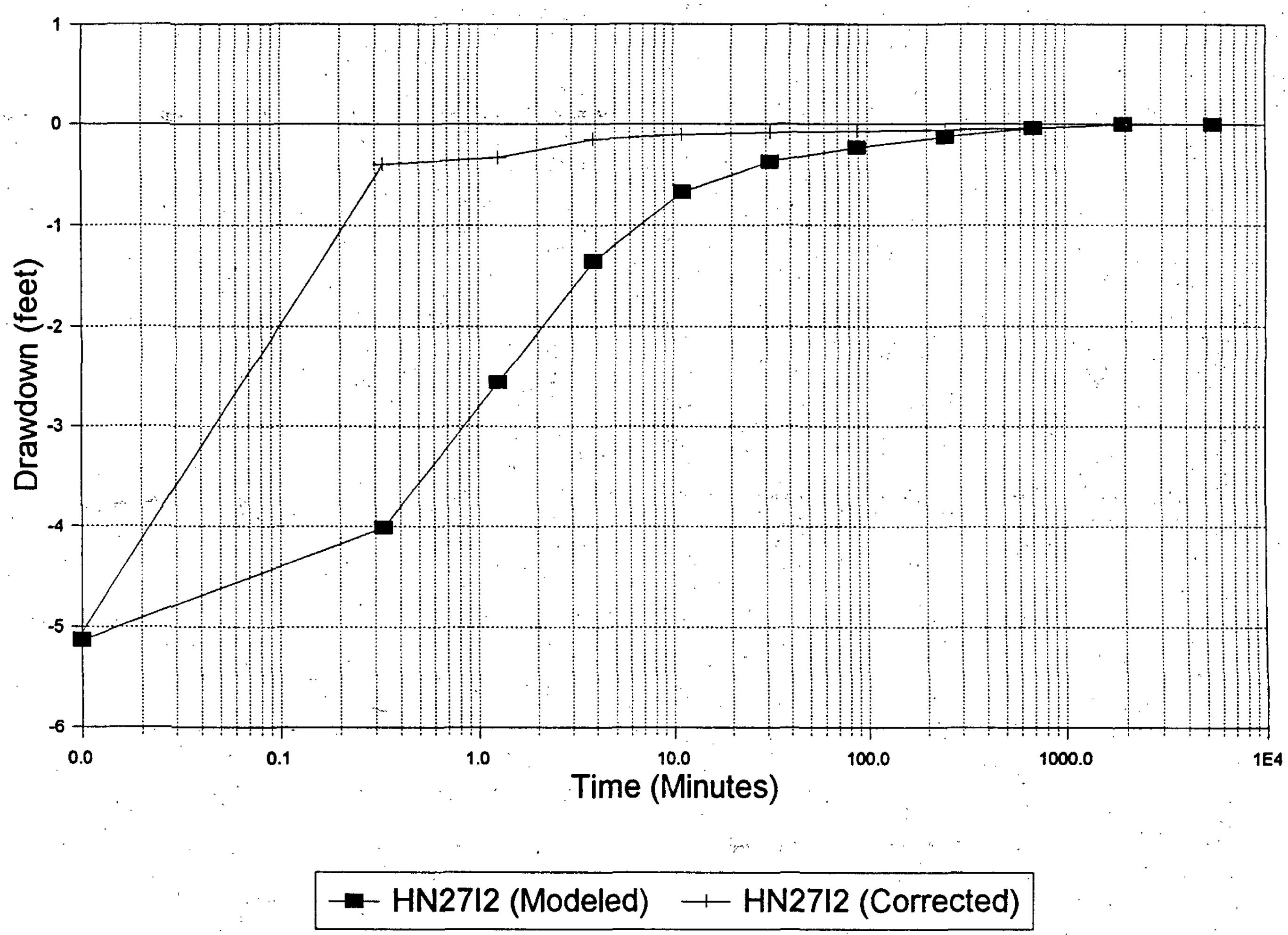
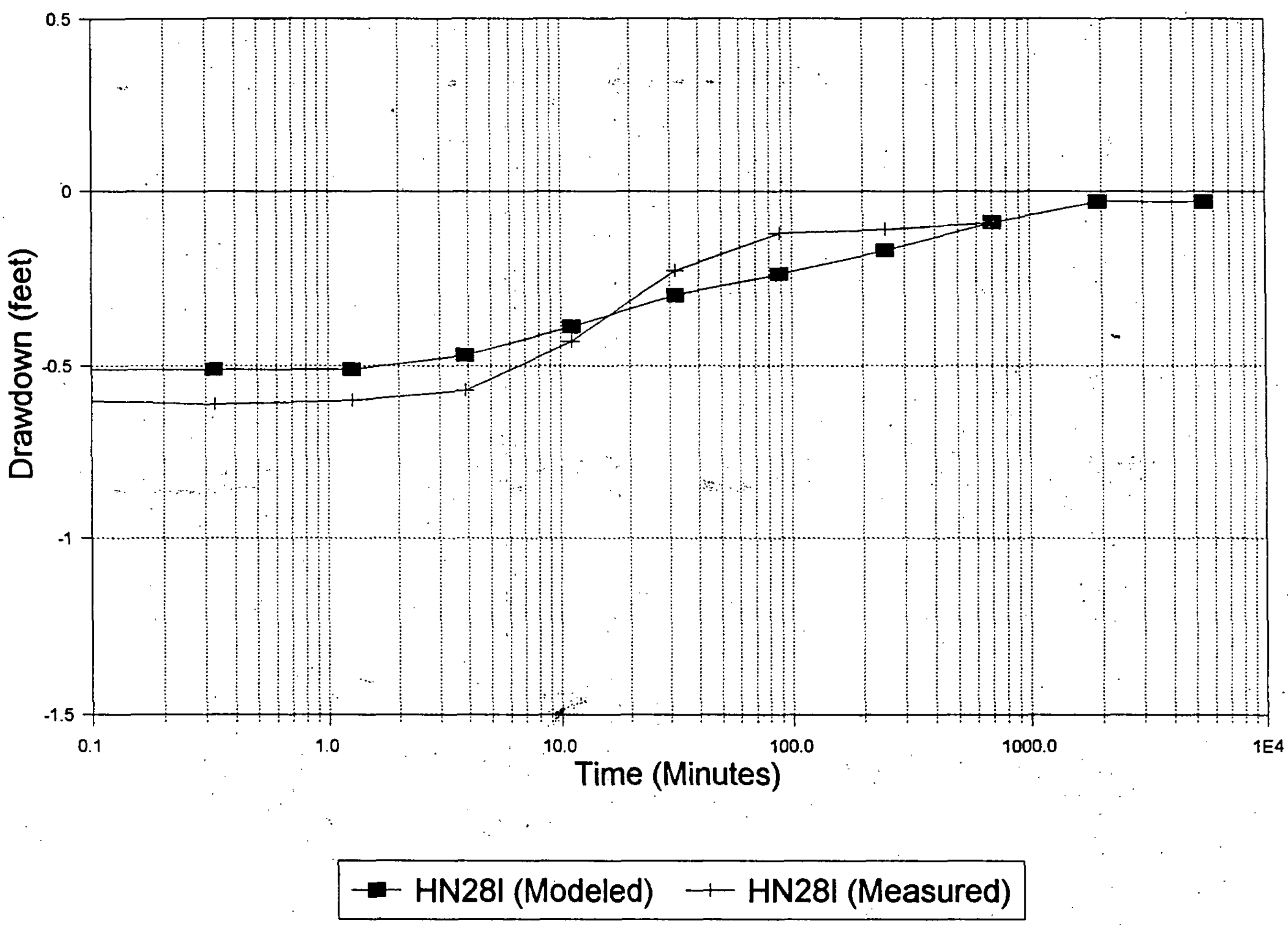


Figure 6-19
HN28I Recovery for Pump Test #1



calibration parameters for the model represent a best-fit for transient and steady-state flow conditions. Final calibrated model simulations had a MODFLOW water balance error of less than 0.15%.

Measured results for pump test #1 show significant drawdown (>1.0 ft) in 4 of the 6 observation wells. The pumping well had 5.05 ft of drawdown (corrected) occurring in the pumping well. The measured drawdown in the pumping well for both pump tests was corrected to account for the drawdown produced within the well casing, which is much higher than was actually produced in the aquifer. This correction was necessary to determine the amount of drawdown which actually occurred in the aquifer immediately outside the pumping wells which is simulated by the model, rather than the amount of drawdown inside the well casing, which was measured during the pumping test. This correction (described in Appendix E) involved determining the actual amount of drawdown which occurred at the well (determined from a distance-drawdown plot), comparing it to the measured drawdown in the pumping well, and using the ratio between actual and measured as a multiplier for the measured drawdown in the well. Use of this correction compensates for the drawdown produced in the well casing while maintaining the same shape of the time-drawdown curve for the pumping wells

As shown in Table 6-5, the modeled results for pump test #1 correspond closely to measured results at the pumping well and the five observation wells. In addition, the graphs comparing the simulated drawdowns and recovery results to the measured data for pump test #1 also show similar modeled and measured results. The total amount of drawdown and the general shape of the drawdown and recovery curves are similar between the modeled and measured results, indicating that the model can successfully reproduce the pumping test results under transient conditions.

As detailed in Appendix E, pumping test #2 did not produce significant drawdowns in observation wells. Small amounts of drawdowns were seen in the observation wells, with <0.5 ft change in head being observed during the pumping test in all of the observation wells. This small amount of drawdown is difficult for the model to simulate for several reasons. Specifically, model drawdowns produced at well nodes are composite values of drawdowns over the entire 100 ft by 100 ft grid block. Small changes in drawdown observed in the natural system may be too small to be simulated effectively, as the model assumes that the location of each observation well corresponds to the center of that grid node. This assumption, inherent in any block-centered flow model, can cause difficulty when trying to simulate small changes in head or drawdowns. In addition, the production well screen is located several hundred feet below the observation wells, which can also add error in the model predictions when attempting to simulate small-scale changes in head. An additional well with an unknown location was also cycling on and off during this pumping test, which effected total drawdowns seen in the observation wells (as described in Appendix E). Because the location and pumping rate of this well is unknown, this additional well could not be added to the model simulations. For these reasons, no comparison of modeled to measured drawdowns was made during the duration of this pumping test. Calibration of pumping test #2 was considered complete when the modeled drawdown was within the 1.0 calibration criteria. Table 6-5 summarizes calibration results of pumping test #2.

6.4 FINAL CALIBRATION VALUES OF AQUIFER PARAMETERS

The final values of horizontal hydraulic conductivity and vertical hydraulic conductivity for layers 1 through 5 are summarized in Figures 6-20 through 6-24. Storage values were constant for all grid blocks in each model layer. Layer 1 had a constant storage value of 0.05, and layers 1 through layer 5 have a constant storage value of 0.0012. A constant porosity of 0.20 was assumed for all model layers. The constant head elevations used in all model simulations are given in Table 6-6.

6.5 STATISTICAL ANALYSIS OF MODEL CALIBRATION RESULTS

To determine if the model data generated during calibration compares favorably to measured data, the results of the calibration were evaluated both qualitatively and quantitatively. The output of the final calibration run for the two steady-state simulations, and the two transient pumping test simulations were analyzed by plotting a linear regression of the modeled data to determine how well the modeled data set compared to the measured data set. To qualitatively determine if any systemic errors exist in the modeled water data (i.e., if consistently high or low regions are present), residual contour plots were generated for the steady-state calibration runs. For both the linear regression and residual contour analysis, the outlier wells were not included, as these wells may have been biased by localized pumping or recharge effects.

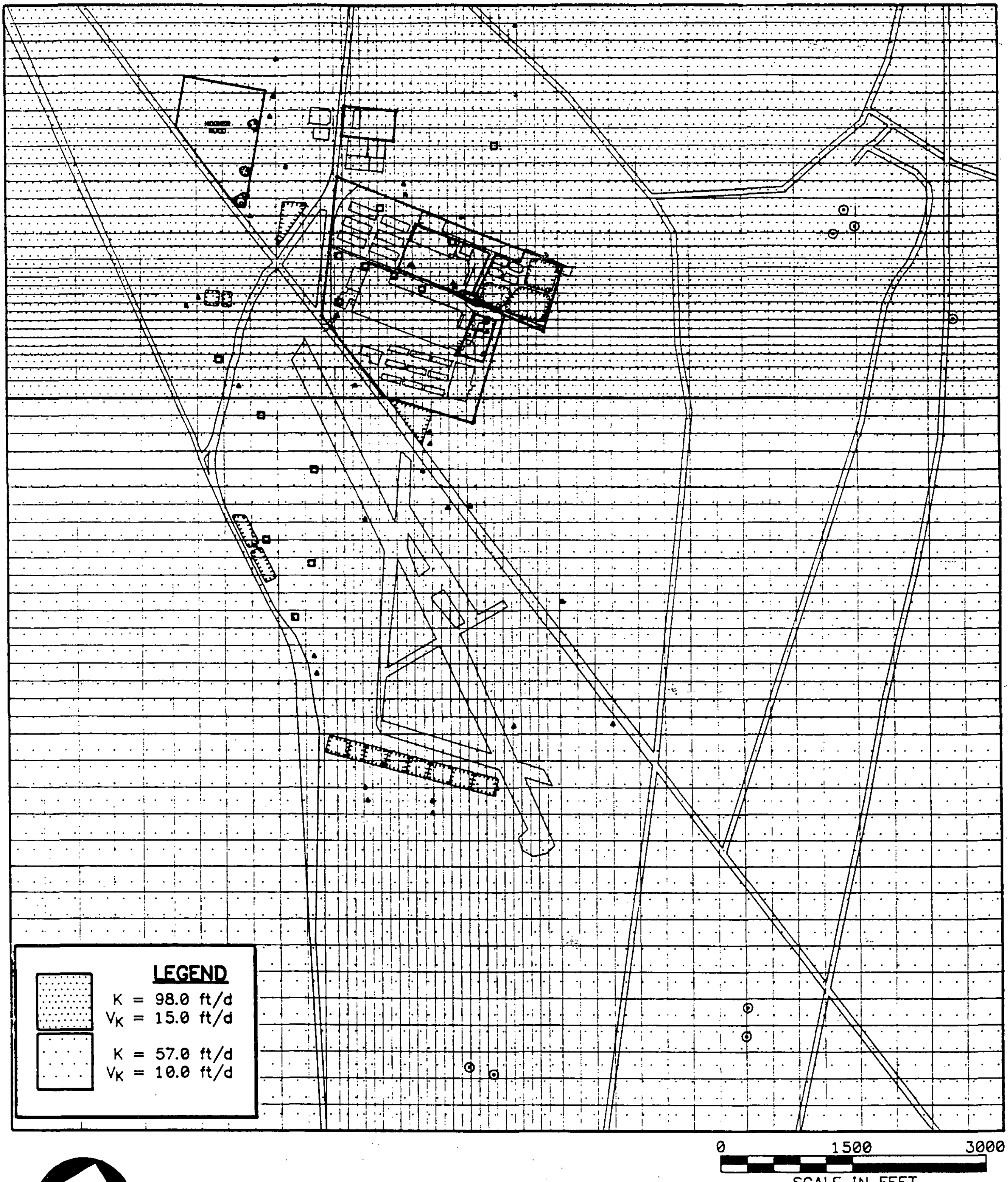
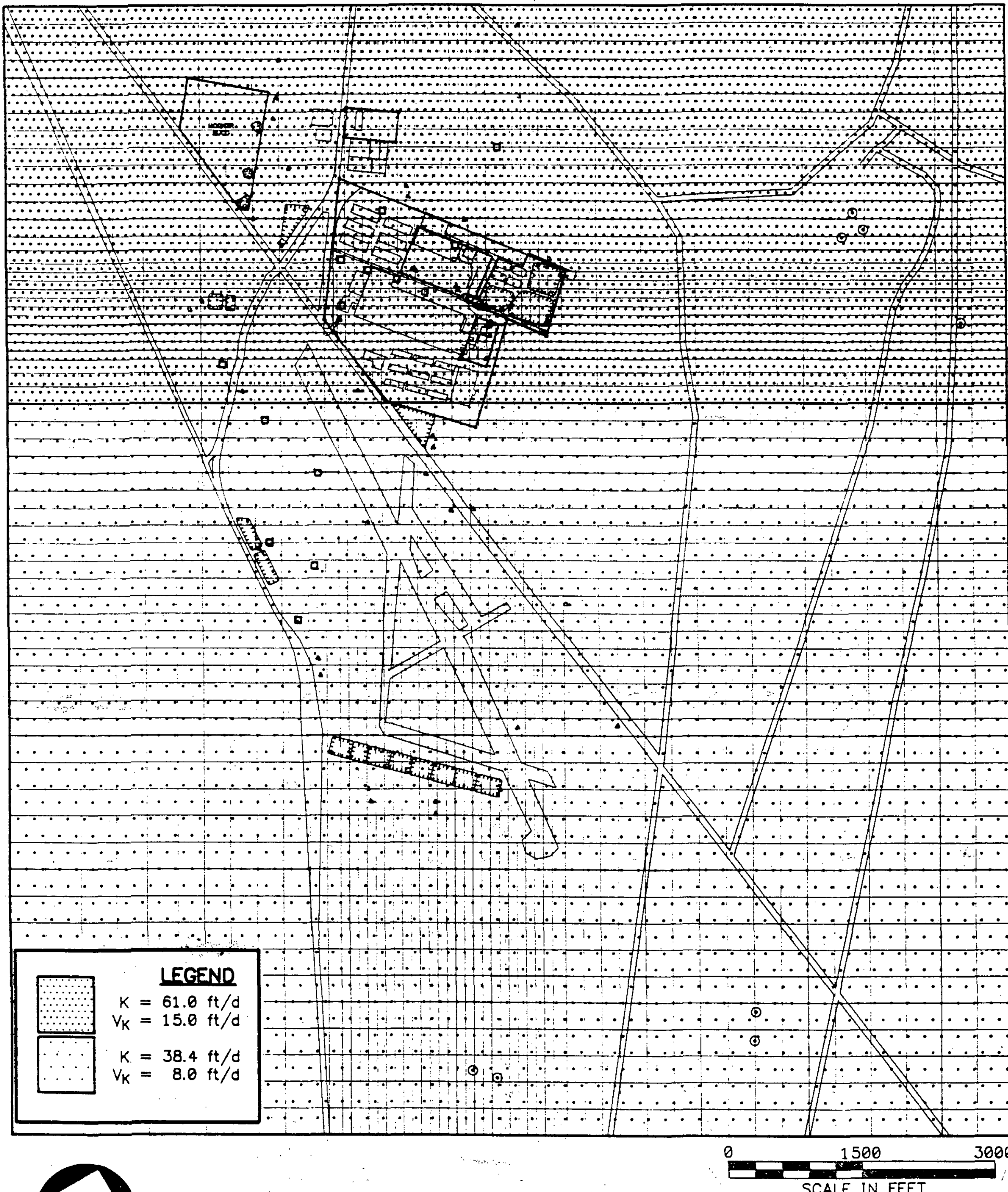


FIGURE 6-20

FINAL CALIBRATION VALUES
LAYER 1
HORIZONTAL/VERTICAL CONDUCTIVITY
BETHPAGE NWIRP

HALLIBURTON NUS
Environmental Corporation

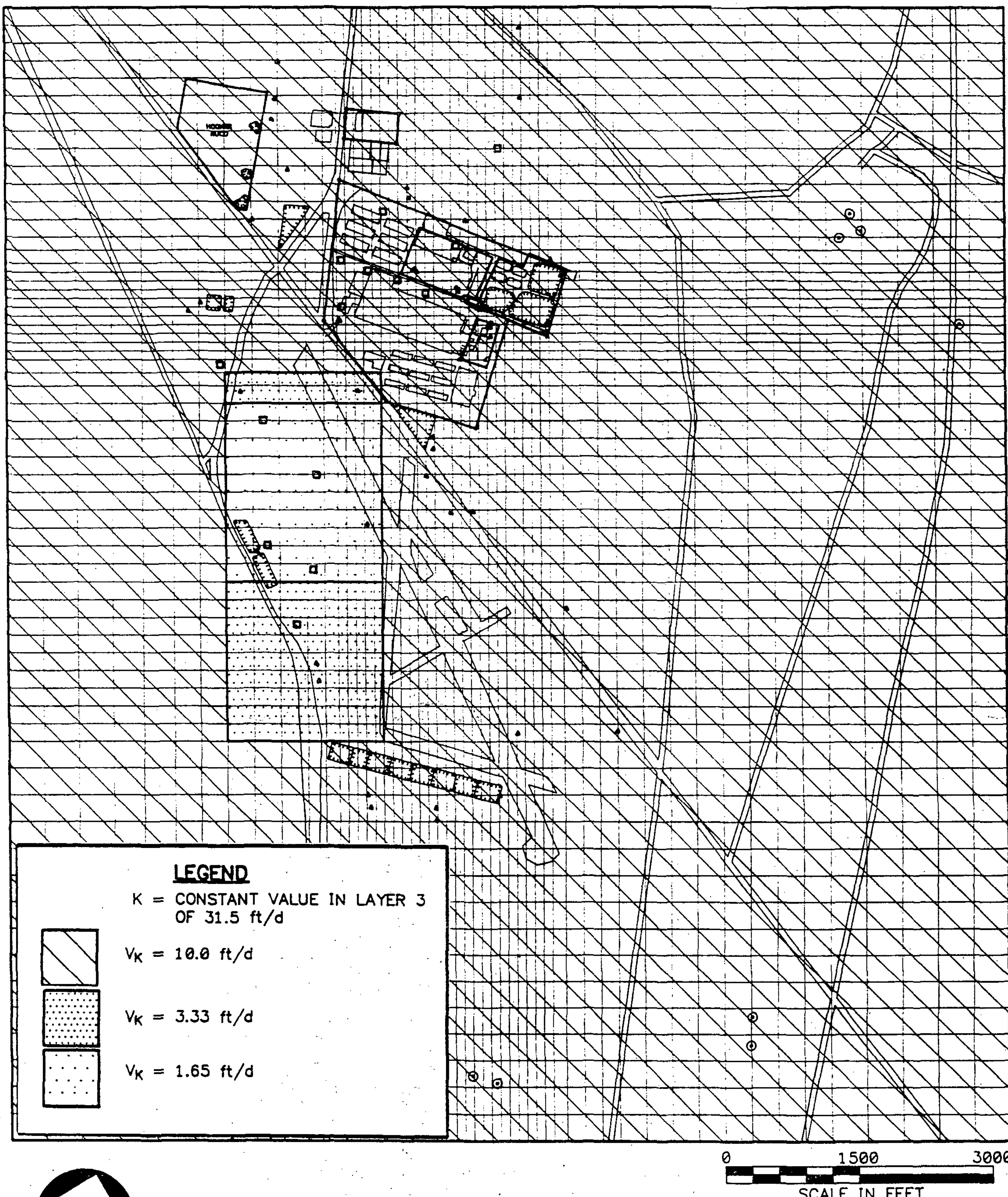
ACAD: 1953\OTHER.DWG 5/27/95 MB (1500)



FINAL CALIBRATION VALUES
LAYER 2
HORIZONTAL/VERTICAL CONDUCTIVITY
BETHPAGE NWIRP

FIGURE 6-21

HALLIBURTON NUS
Environmental Corporation

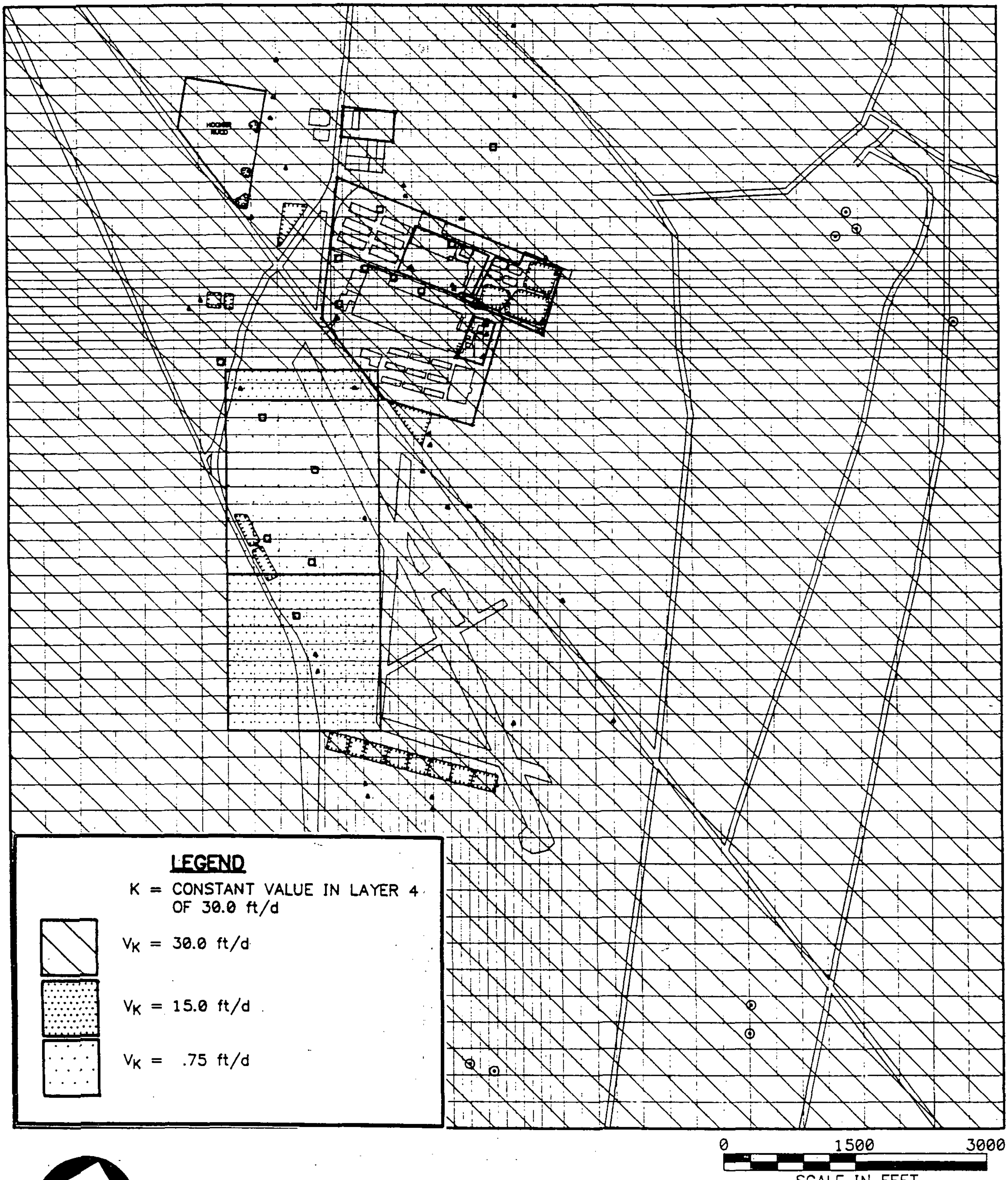


FINAL CALIBRATION VALUES
LAYER 3
HORIZONTAL/VERTICAL CONDUCTIVITY
BETHPAGE NWIRP

FIGURE 6-22

HALLIBURTON NUS
Environmental Corporation

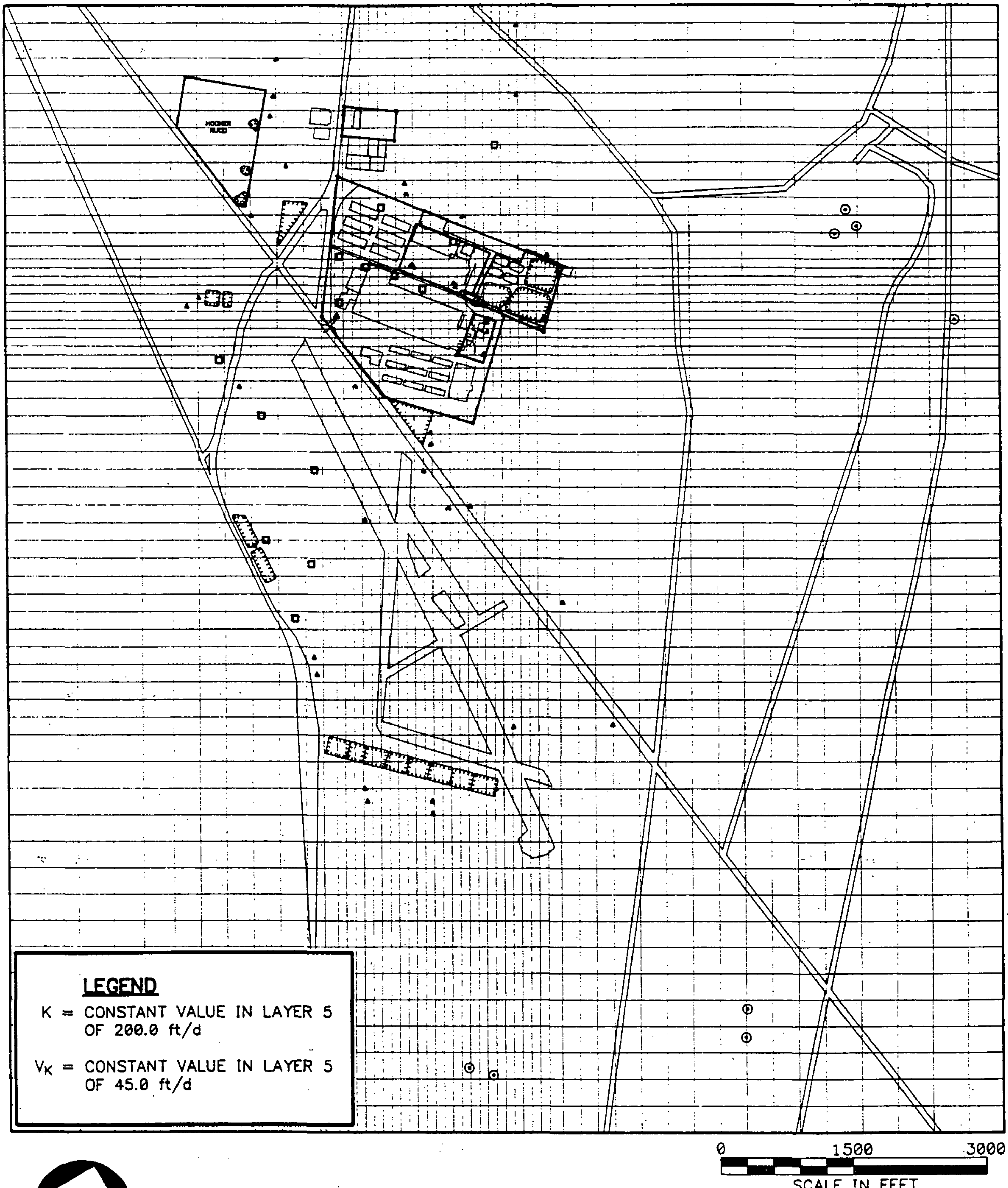
ACAD: 1955\OTHER.DWG 5/27/93 MB (1500)



FINAL CALIBRATION VALUES
LAYER 4
HORIZONTAL/VERTICAL CONDUCTIVITY
BETHPAGE NWIRP

FIGURE 6-23

HALLIBURTON NUS
Environmental Corporation



FINAL CALIBRATION VALUES
LAYER 5
HORIZONTAL/VERTICAL CONDUCTIVITY
BETHPAGE NWIRP

FIGURE 6-24

HALLIBURTON NUS
Environmental Corporation

TABLE 6-6
CALIBRATION VALUES OF NORTH AND SOUTH CONSTANT HEAD BOUNDARY ELEVATIONS

LOW PUMPING CONDITIONS - FEBRUARY 1992

NORTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)		
COLUMN #	LAYER 1	LAYER 2
1-2	76.90	76.00
3-10	77.30	76.40
11-20	77.05	76.15
21-30	77.35	76.45
31-35	76.85	75.95
36-38	77.35	76.45
39-41	77.85	76.95
42-47	79.2	78.3
48-53	79.30	78.40
SOUTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)		
COLUMN #	LAYER 1	LAYER 2
ALL	62.10	61.60

NORTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)			
COLUMN #	LAYER 3	LAYER 4	LAYER 5
1-2	71.95	71.85	71.75
3-10	72.35	72.25	72.15
11-22	72.60	72.50	72.4
23-34	73.15	73.05	72.95
35-40	73.85	73.75	73.65
41-53	74.35	74.15	74.05
SOUTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)			
COLUMN #	LAYER 3	LAYER 4	LAYER 5
ALL	59.85	59.75	59.65

HIGH PUMPING CONDITIONS - AUGUST 1992

NORTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)		
COL #	LAYER 1	LAYER 2
1-2	74.55	73.55
3-10	74.95	73.95
11-20	74.70	73.70
21-30	75.00	74.00
31-35	74.50	73.50
36-38	75.00	74.00
39-41	75.5	74.5
42-47	76.85	75.85
48-53	76.95	75.95
SOUTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)		
COLUMN #	LAYER 1	LAYER 2
ALL	61.00	60.50

NORTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)			
COLUMN #	LAYER 3	LAYER 4	LAYER 5
1-2	70.10	70.00	69.9
3-10	70.50	70.40	70.3
11-22	70.75	70.65	70.55
23-34	71.30	71.20	71.1
35-40	72.00	71.90	71.8
41-53	72.50	72.30	72.2
SOUTH CONSTANT HEAD BOUNDARY ELEVATION (ft amsl)			
COLUMN #	LAYER 3	LAYER 4	LAYER 5
ALL	58.85	58.75	58.65

amsl = Feet Above Mean Sea-Level.

6.5.1 Linear Regression

A linear regression was performed for the two pumping test simulations and the February and August 1992 data. Modeled water elevations were plotted against measured water elevations, and a regression line for the points was calculated using the least-squared method. Figures 6-25 and 6-26 show the linear regressions for the February and August 1992 data. The slope of the regression line indicates if a direct relationship exists between the dependant and independent variables. A slope of 1.0 indicates a direct relationship.

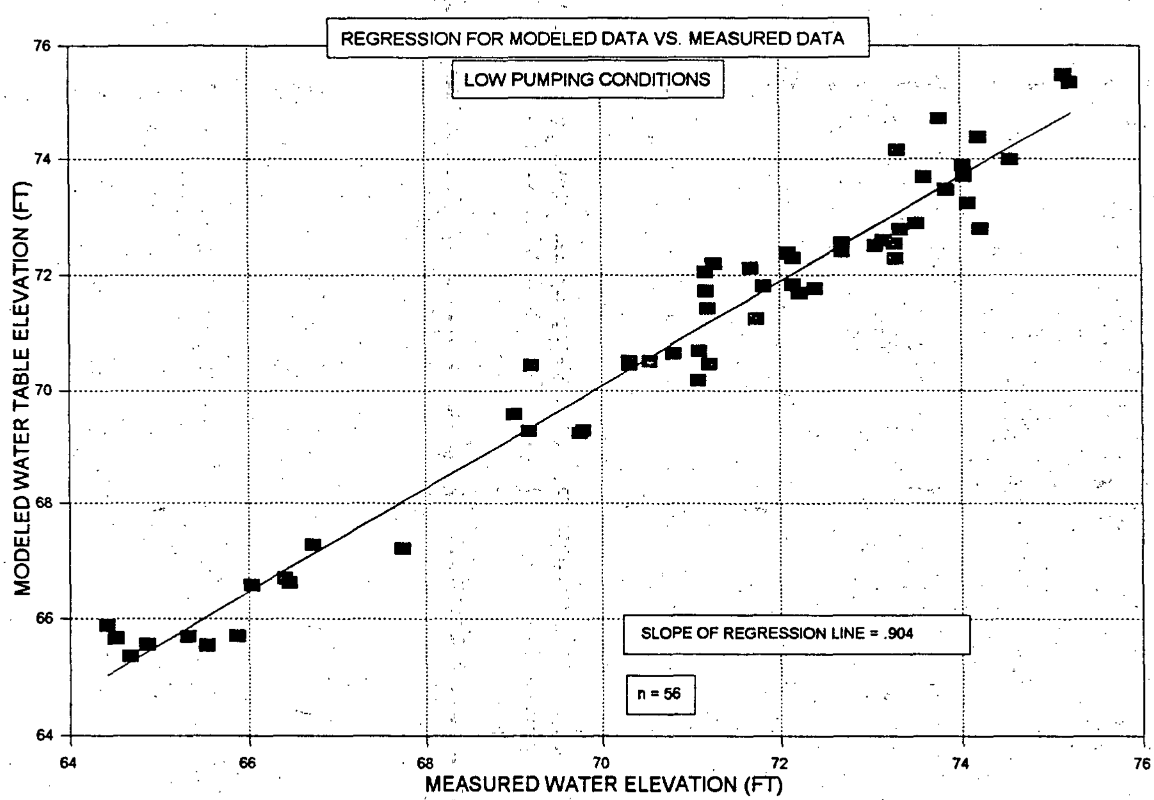
The slope of the regression line for the February 1992 data has a slope of 0.904, and the slope of the line for the August 1992 data has a slope of 0.981. When both data sets are combined, as illustrated in Figure 6-27, the slope of the regression line is 0.946. The regression lines for all steady-state data sets indicate a close to linear relationship for the measured and modeled data. Water elevation is a function of location within the model grid with higher elevations being present in the northern portion of the site and lower elevations towards the south. The nearly direct relationship of measured to modeled data for the entire range of water elevations indicates that model accuracy does not decrease with higher or lower values of water elevation across the site.

Figures 6-28 and 6-29 show the regressions for pump test #1 and pump test #2 drawdowns. The regression line for pumping test #1 drawdown data has a slope of 1.036 and shows a tight clustering of data around the regression line, which indicates a very close relationship between measured and modeled drawdown data. Due to the difficulty in simulating the small amount of drawdown produced in pumping test #2, the slope of this regression line for this data has a slope of 1.994 and shows scatter of data points around the regression line.

6.5.2 Residual Contours

A residual contours plot shows the distribution of model error over the model area for a given pumping scenario. Residual contour plots are useful for determining if trends are present in the distribution of model error over the grid. If trends of significantly high or low model error are seen in the residual contour plots in more than one pumping condition in a specific area, it may indicate aquifer parameters in that area need to be adjusted to eliminate these errors or adjustments need to be made to the

Figure 6-25



REGRESSION FOR MODELED DATA VS. MEASURED DATA
LOW PUMPING CONDITIONS
MODELED WATER TABLE ELEVATION (FT)
MEASURED WATER ELEVATION (FT)
SLOPE OF REGRESSION LINE = .904
n = 56
76
74
72
70
68
66
64
64
66
68
70
72
74
76

Figure 6-26

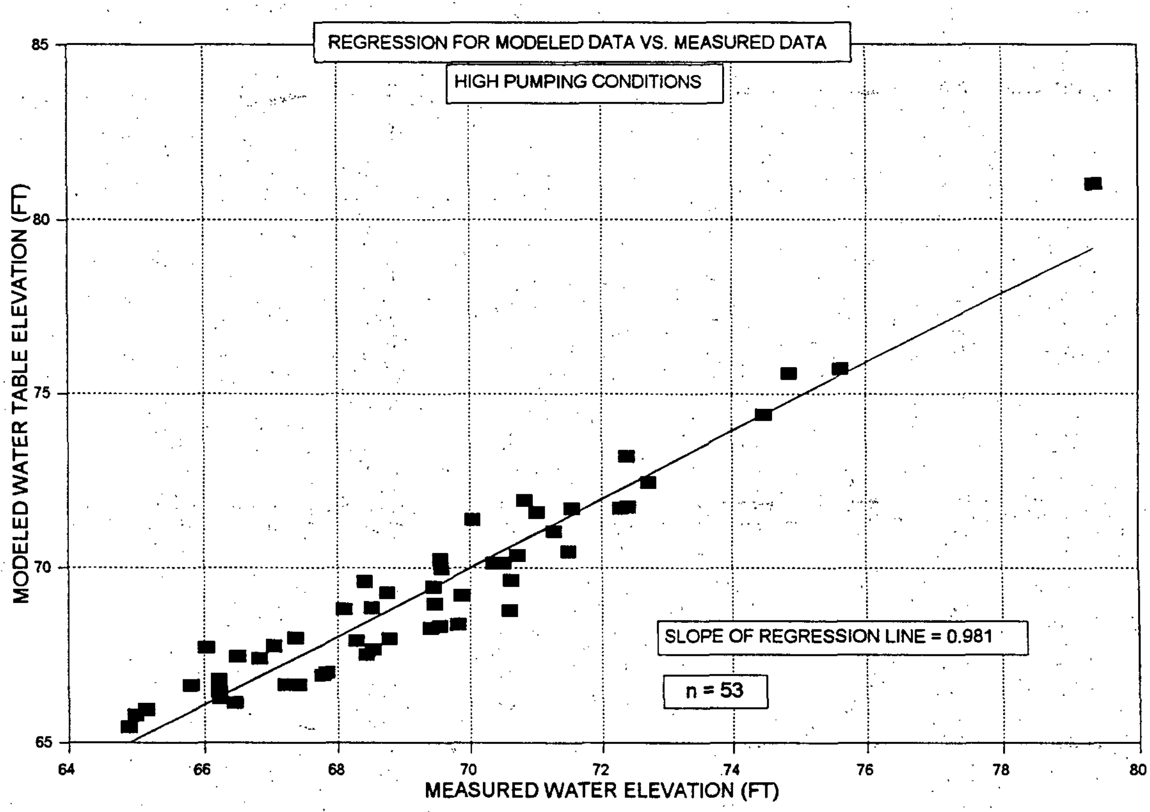

REGRESSION FOR MODELED DATA VS. MEASURED DATA
HIGH PUMPING CONDITIONS
MODELED WATER TABLE ELEVATION (FT)
85
80
75
70
65
64
66
68
70
72
74
76
78
80
MEASURED WATER ELEVATION (FT)
SLOPE OF REGRESSION LINE = 0.981
n = 53

Figure 6-27

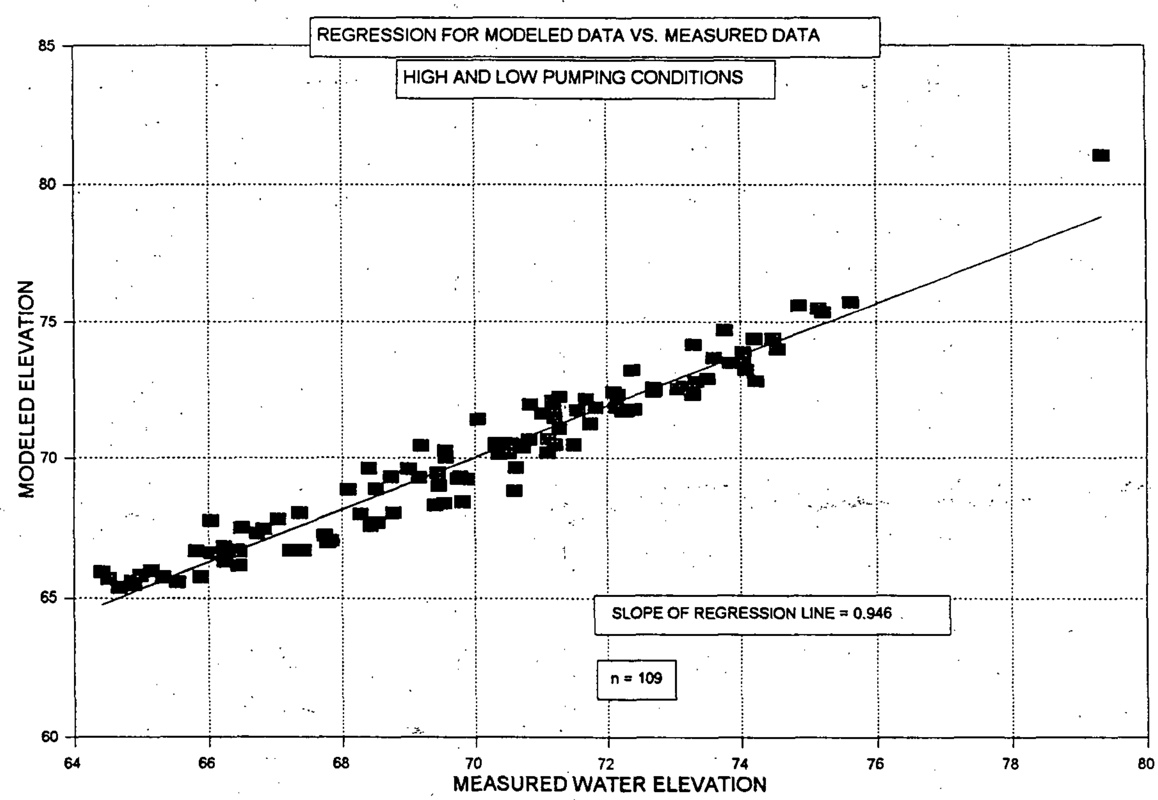
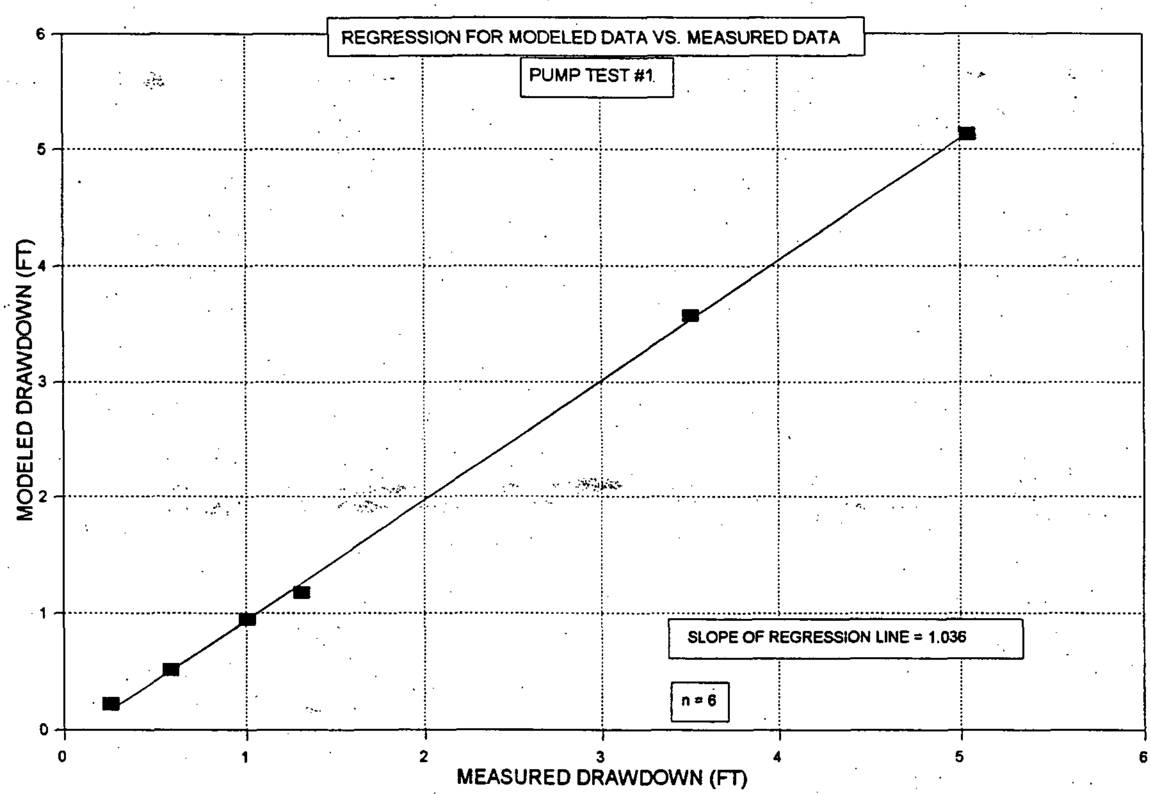
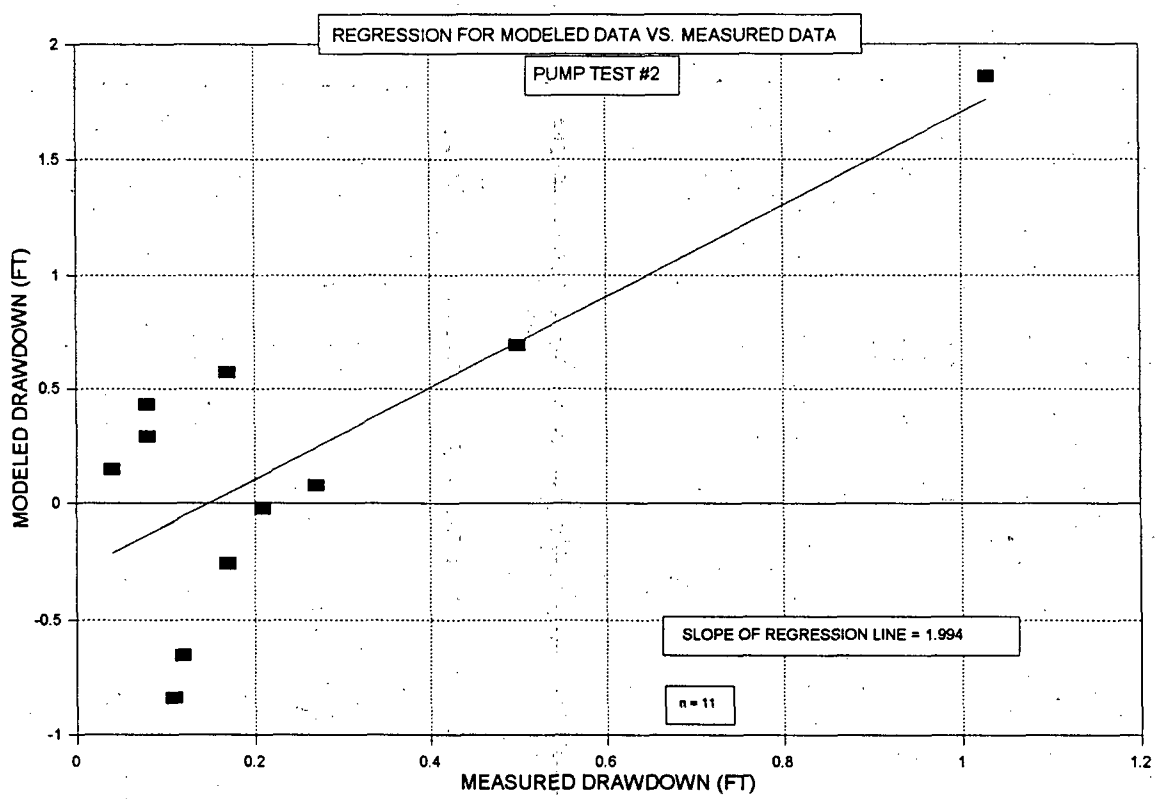

REGRESSION FOR MODELED DATA VS. MEASURED DATA
HIGH AND LOW PUMPING CONDITIONS
85
80
75
70
65
60
MODELED ELEVATION
64
66
68
70
72
74
76
78
80
MEASURED WATER ELEVATION
SLOPE OF REGRESSION LINE = 0.946
n = 109

Figure 6-28



REGRESSION FOR MODELED DATA VS. MEASURED DATA
PUMP TEST #1
SLOPE OF REGRESSION LINE = 1.036
n = 6
MODELED DRAWDOWN (FT)
MEASURED DRAWDOWN (FT)
0
1
2
3
4
5
6

Figure 6-29



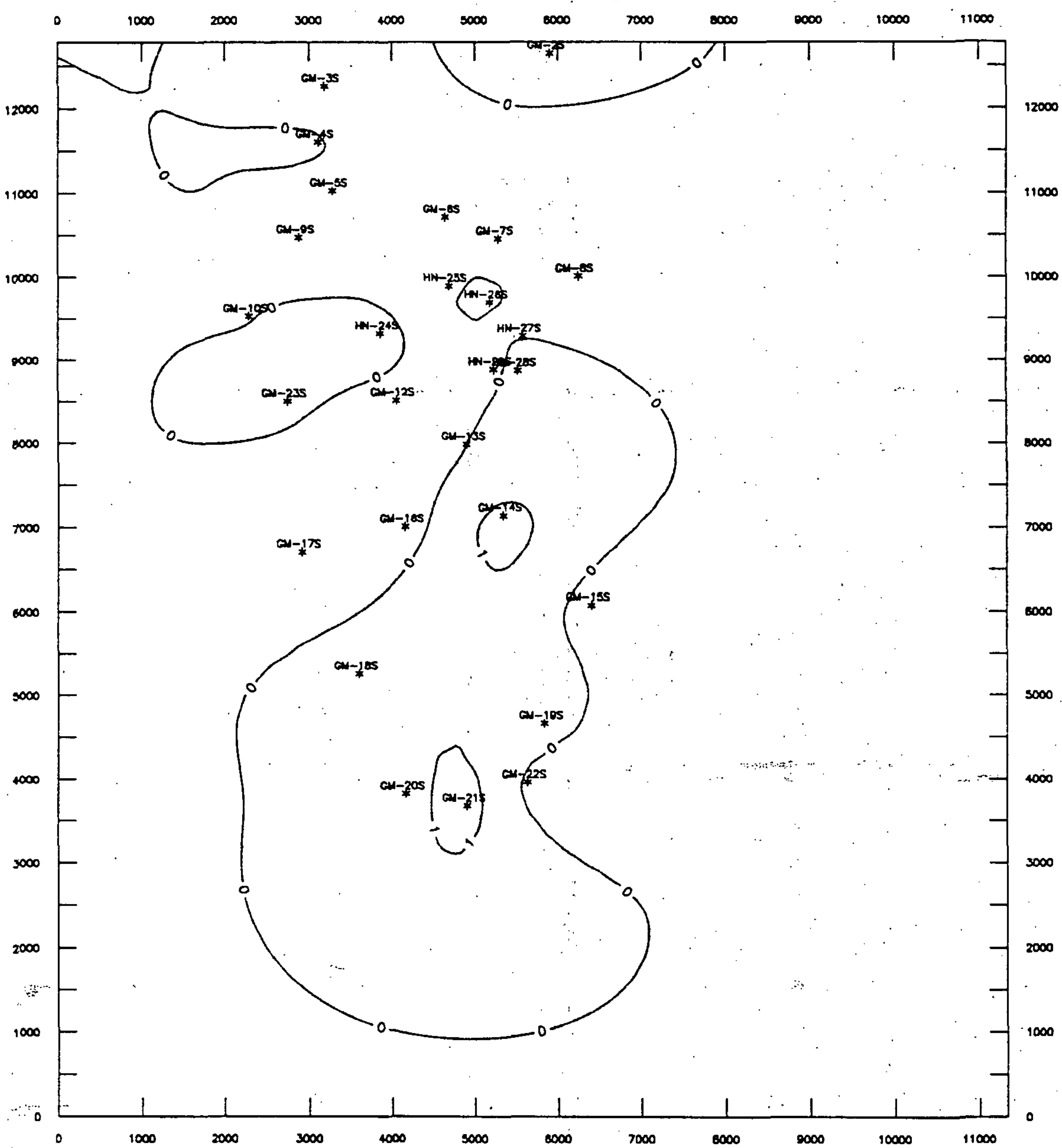
REGRESSION FOR MODELED DATA VS. MEASURED DATA
PUMP TEST #2
MODELED DRAWDOWN (FT)
MEASURED DRAWDOWN (FT)
SLOPE OF REGRESSION LINE = 1.994
n = 11
2
1.5
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
1.2

production well or recharge rates in the area.

Residual contours were produced by entering the difference of modeled to measured values for water elevation (error expressed in feet) into the contouring package, SURFER. For both the February and August 1992 pumping conditions a separate plot was made for layer 1 and layer 2, using shallow and intermediate well error data. Insufficient numbers of deep wells exist on the site for a residual contour plot to be constructed for layer 3. Figures 6-30 and 6-31 show the residual contour plots for layer 1 and layer 2 of the calibrated February 1992 pumping conditions. Figures 6-32 and 6-33 show the residual contour plots for layer 1 and layer 2 of the calibrated August pumping conditions.

Generally, model errors across the site do not show significant trends between pumping scenarios. Areas of ±1.0 ft model error were considered to be within acceptable levels of error as they are well below the ±2.0 ft calibration criteria. Regions of greater than 1.0 ft positive model error are evident in the GM-21 region in the shallow and intermediate plots of the February 1992 model data. Areas of more than 1.0 ft negative model error are present in the vicinity of GM-13 and HN-25 in the shallow and intermediate plots of the August 1992 model data. These areas of slightly higher model error were not considered to be a concern, because the wells in these area were within the calibration criteria, and during model calibration attempts were made to correct these areas of model error. Also, these trends in model error are not consistent across pumping conditions and may represent increased pumpage or recharge at the production wells and recharge basins in the vicinity of these wells during the time period when water elevations were measured. The model simulations assume a constant pumping and recharge rate throughout the month, and short-term changes in pumping or recharge rates could effect the modeled vs. measured results.

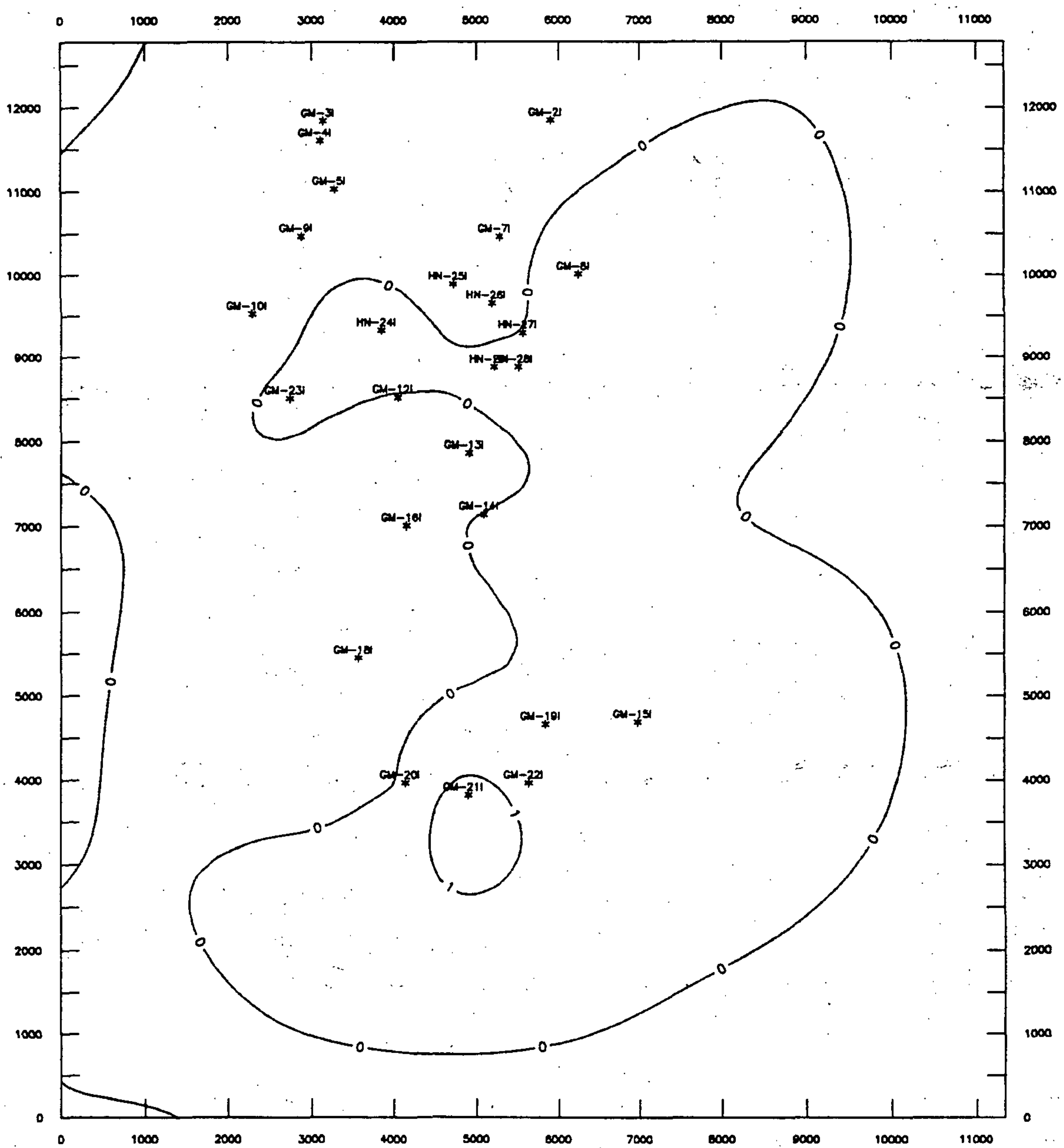
Figure 6-30
Residual Contour Plot - February, 1992 - Layer 1



* = Production Well Location
\+ = HNUS or Geraghty & Miller Monitoring Well

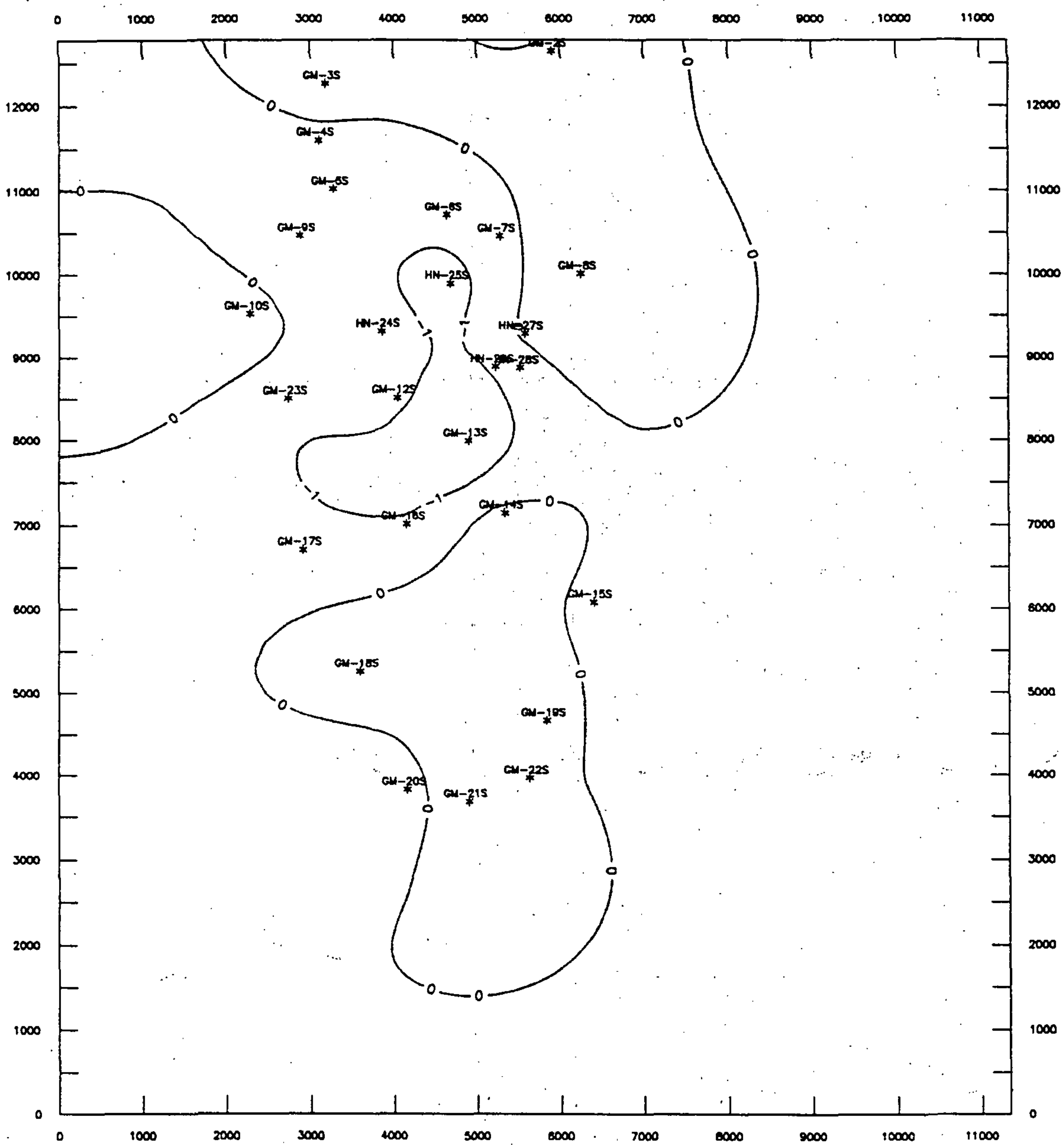
SCALE 1 inch = 2130 ft

Figure 6-31
Residual Contour Plot - February, 1992 - Layer 2



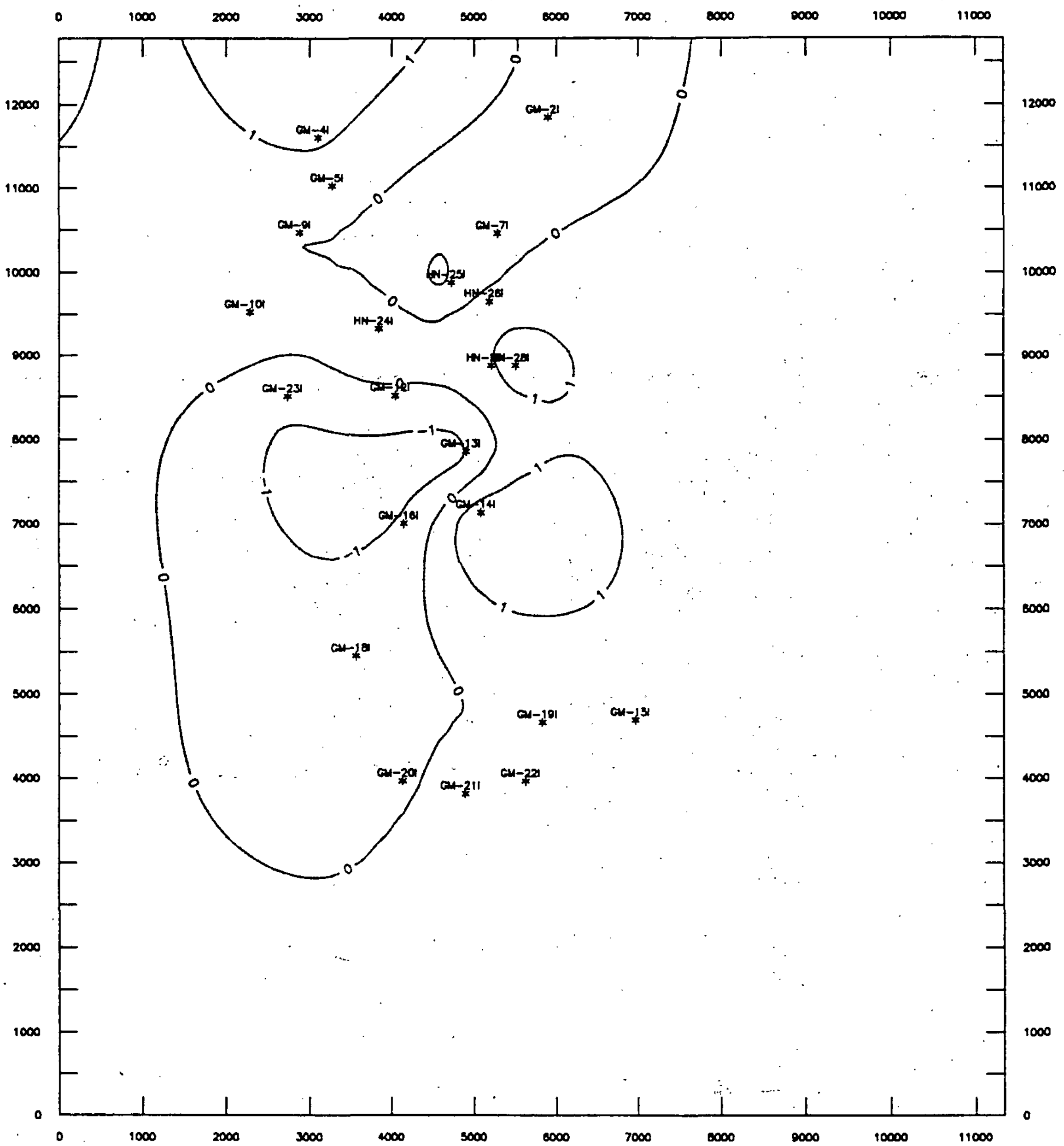
* = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 6-32
Residual Contour Plot - August, 1992 - Layer 1.



* = Production Well Location
\+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 6-33
Residual Contour Plot - August, 1992 - Layer 2.



* = Production Well Location
\+ = HNUS or Geraghty & Miller Monitoring Well

SCALE 1 inch = 2130 ft

7.0 MODEL VALIDATION

Model validation is a check on how well the model can predict a set of water elevations, utilizing the model parameters established during model calibration. Validation helps establish confidence in the model by predicting the heads at observation points within the acceptable levels of error given a set of pumping conditions. Model validation for the MODFLOW model consisted of entering the known pumping rates for production wells and recharge basins for two separate months, running the model to a steady-state, and comparing model output to measured data for those months. Two validation scenarios for January and July 1992 were simulated.

7.1 VALIDATION PROCEDURES

Two data sets of Grumman production well data and site wide monitoring well data were utilized (January 1992 and July 1992). These two data sets were not used during model calibration and represent independent data sets for model validation. The January 1992 and July 1992 data sets were chosen for validation because these months occur immediately before February and August, 1992, which were used during calibration. The January 1992 and July 1992 data was considered to represent the most similar boundary conditions to those used for calibration, as they occur in the same seasons as the calibration runs. Precipitation data indicates that January and July are more similar to February and August, than March and September (the other months considered for validation). Using months in similar seasons, with similar amounts of precipitation for calibration and validation is important because the total precipitation will effect the water elevations at the northern and southern constant head boundaries, which effect water elevations across the modeled area.

For each validation scenario, the Grumman production well data was input into the model, and run to a steady-state. The model output was then compared to measured results at each monitoring well. Pumping rates for Grumman production wells were determined from the monthly totals for each well. All of the water pumped from the production wells was assumed to be recharged into the Grumman recharge basins. Hooker-Ruco recharge basins were assigned the same recharge rates as those used in the February and August 1992 calibration runs. Pumping and recharge rates used for the January and

July, 1992 validation scenarios are listed in Table 7-1. The recharge basin at GM-15S was not active during the January, 1992 validation run, as water levels indicate that this activity did not begin until February 1992 (see Figure 6-1). The GM-15S basin was active in the July 1992 simulation at the recharge rate determined during the August 1992 calibration run.

All other model parameters, such as recharge, horizontal and vertical hydraulic conductivity, were identical to those used in model calibration. The January 1992 validation was performed using February 1992 boundary conditions, while the July 1992 validation was performed using the August 1992 boundary conditions.

7.2 VALIDATION RESULTS

Tables 7-2 and 7-3 present the results of model validation for January and July, 1992 scenarios. Figures 7-1 and 7-2 graphically illustrate the amount of model error for each monitoring well at the site.

The January 1992 validation run results show that the difference between the modeled and measured water elevations falls within the ±2.0 ft criteria for 56 of 58 monitoring wells. Two wells (GM-6I and GM-17S) fall outside the ±2.0 ft criteria. These wells are in the immediate vicinity of a production well and recharge basin and, as discussed in Section 6.2.2, are considered outlier wells and were not included in calculation of mean error because they may be effected by pumping or recharge activity.

Results of the July, 1992 validation run show that the difference between the modeled and measured water elevations fall within the ±2.0 ft criteria for the majority of the monitoring wells. Five wells, GM-6I, GM-17S, HN-8D, HN-29D and HN-30I, are in the immediate vicinity of a production well or recharge basins, and as discussed in Section 6.2.2, are considered outlier wells and were not included in calculation of mean error because they may be effected by pumping or recharge activity. As shown in Figure 7-2, three monitoring wells, GM-7D, GM-8S and HN-28I showed a modeled to measured difference of greater than ±2.0 ft. The remaining 51 of 59 monitoring wells fall within the ±2.0 ft criteria.

Due to the nature of the validation process, no aquifer parameters were altered between the calibration runs and the validation runs, including the constant head elevations. The seasonal variation of constant head elevations which is suspected to exist in the natural system, was not accounted for in model

TABLE 7-1
PRODUCTION WELL PUMPING RATES USED IN MODEL VALIDATION SIMULATIONS

PRODUCTION WELL	LOCATION (ROW,COL.)	LAYER	% PUMPED FROM LAYER	JANUARY, 1992 (1)		JULY, 1992 (1)	
				Actual Pumping rate (gpm)	Model Pumping rate (gpm)	Actual Pumping rate (gpm)	Model Pumping rate (gpm)
SOUTH PRODUCTION WELLS							
PW-1	42, 10	5	100%	781	781	1,093	1,093
PW-2	34, 11	5	100%	0	0	0	0
PW-3	38, 9	5	100%	0	0	0	0
PW-4	39, 11	4	100%	0	0	0	0
PW-5	31, 9	4	100%	0	0	1	1
PW-6	27, 7	3	11%	0	0	94	94
		4	89%	0	0	759	759
SOUTH PRODUCTION WELL TOTALS:				781	781	1,947	1,947
SOUTH RECHARGE BASINS - OUTFALLS 005, 006 AND 007							
23 GRID BLOCKS (2)	--	1	100%	34	34	85	85
NORTH PRODUCTION WELLS							
PW-8	15, 13	4	16%	0	0	1	1
		5	84%	0	0	6	6
PW-9	16, 16	4	100%	524	524	929	929
PW-10	18, 19	4	100%	1	1	797	797
PW-11	19, 23	4	37%	0	0	205	205
		5	63%	0	0	349	349
PW-13	12, 18	5	100%	0	0	817	817
PW-14	21, 13	4	62%	0	0	0	0
		5	38%	0	0	0	0
PW-15	14, 26	5	100%	0	0	468	468
PW-16	9, 31	4	100%	839	839	810	810
NORTH PRODUCTION WELL TOTAL:				1,364	1,364	4,382	4,382
NORTH RECHARGE BASINS - OUTFALLS 004 AND 010							
24 GRID BLOCKS (2)	--	1	100%	57	57	183	183
OTHER BASINS							
GM-15S BASIN	41, 38	1	100%	(3)	0	(3)	306
HOOKER-RUCO BASINS AVERAGE		1	100%	(3)	202	(3)	838

(1) MONTHLY PUMPING RATE FROM GRUMMAN AEROSPACE DATA.
(2) CALCULATIONS ARE TOTALS FOR EACH BASIN GRID BLOCK.
(3) RECHARGE RATE DATA NOT AVALIABLE FOR HOOKER-RUCO OR GM-15S RECHARGE BASINS.

TABLE 7-2
MODEL VALIDATION RESULTS
JANUARY 1992

WELL	GRID LOCATION (R,C,L)	JAN. 24, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
GM-2S	2, 33, 1	75.75	75.49	-0.26
GM-2I	6, 33, 2	74.97	73.22	-1.75
GM-3S	4, 10 1	75.15	74.00	-1.15
GM-3I	6, 9, 2	74.68	73.71	-0.97
GM-4S	7, 9, 1	75.94	75.37	-0.57
GM-4I	7, 9, 2	74.53	73.90	-0.63
GM-5S	10, 10, 1	74.20	72.92	-1.28
GM-5I	10, 10, 2	73.96	72.81	-1.15
GM-6S	11, 21, 1	73.88	72.32	-1.56
GM-6I (1)	*11, 21, 2*	*68.69*	*72.27*	*3.58*
GM-7S	13, 27, 1	72.52	72.52	0.00
GM-7I	13, 27, 2	72.10	72.45	0.35
GM-7D	13, 27, 3	71.01	72.30	1.29
GM-8S	15, 37, 1	74.30	74.04	-0.26
GM-8I	15, 37, 2	71.94	73.62	1.68
GM-9S	13, 9, 1	73.31	72.59	-0.72
GM-9I	13, 9, 2	73.26	72.44	-0.82
GM-10S	20, 7, 1	72.22	71.84	-0.38
GM-10I	21, 6, 2	72.25	71.29	-0.96
GM-12S	29, 15, 1	71.70	70.73	-0.97
GM-12I	29, 15, 2	71.33	70.69	-0.64
GM-13S	31, 23, 1	71.06	70.46	-0.60
GM13I	32, 23, 2	71.47	70.13	-1.34
GM-13D	34, 22, 3	68.01	69.53	1.52
GM-14S	32, 28, 1	69.32	70.33	1.01
GM-14I	36, 25, 2	69.71	69.17	-0.54
GM-15S	41, 38, 1	67.29	68.18	0.89
GM-15I	48, 40, 2	66.45	66.41	-0.04
GM-16S	36, 16, 1	68.53	69.23	0.70
GM-16I	36, 16, 2	69.15	69.18	0.03
GM-17S (2)	*38, 9, 1*	*72.49*	*69.74*	*-2.75*
GM-18S	45, 11, 1	67.48	67.24	-0.24
GM-18I	44, 11, 2	67.92	67.36	-0.56
GM-19S	48, 33, 1	66.81	66.68	-0.13
GM-19I	48, 33, 2	66.98	66.58	-0.40
GM-20S	51, 16, 1	66.19	65.89	-0.30
GM-20I	51, 16, 2	65.98	65.69	-0.29
GM-20D	51, 16, 3	64.95	65.44	0.49
GM-21S	51, 23, 1	65.31	66.36	1.05
GM-21I	51, 23, 2	64.93	66.00	1.07
GM-22S	51, 30, 1	66.35	66.02	-0.33
GM-22I	51, 30, 2	67.68	65.78	-1.90
GM-23S	29, 8, 1	71.38	70.55	-0.83
GM-23I	29, 8, 2	71.79	70.51	-1.28

TABLE 7-2
MODEL VALIDATION RESULTS
JANUARY 1992

WELL	GRID LOCATION (R,C,L)	JAN. 24, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
HN-8D	17, 37, 3	--	--	--
HN-24S	13, 22, 1	72.35	72.16	-0.19
HN-24I	13, 22, 2	71.73	72.10	0.37
HN-25S	16, 21, 1	73.07	71.88	-1.19
HN-25I	16+17, 21+22, 2	73.02	71.84	-1.18
HN-25D	16, 21, 3	--	--	--
HN-26S	18, 26, 1	74.51	72.67	-1.84
HN-26I	19, 26, 2	74.24	72.49	-1.75
HN-27S	22+23, 30, 1	74.64	73.71	-0.93
HN-27I	22+23, 30, 2	74.09	73.18	-0.91
HN-28S	26+27, 29+30, 1	72.65	72.10	-0.55
HN-28I	26+27, 29+30, 2	71.91	71.96	0.05
HN-29S	26+27, 26+27, 1	72.76	71.72	-1.04
HN-29I	26+27, 26+27, 2	71.97	71.63	-0.34
HN-29D	26+27, 26+27, 3	--	--	--
HN-30S	22, 36+37, 1	74.05	75.48	1.43
HN-30I	22, 36+37, 2	74.81	73.99	-0.82

NOTE: Calibration Criteria +/- 2.0 ft.
(1) Monitoring well not included in calibration due to proximity to production well.
(2) Monitoring well not included due to proximity to recharge basin.

MEAN ERROR:	-0.41
ABSOLUTE RESIDUAL VALUE:	46.02
MODFLOW WATER BALANCE ERROR:	0.10%

TABLE 7-3
MODEL VALIDATION RESULTS
JULY 24, 1992 PUMPING CONDITIONS

WELL	GRID LOCATION (R,C,L)	JULY 24, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
GM-2S	2, 33, 1	72.10	73.27	1.17
GM-2I	6, 33, 2	71.05	71.41	0.36
GM-3S	4, 10 1	71.46	71.82	0.36
GM-3I	6, 9, 2	70.49	71.78	1.29
GM-4S	7, 9, 1	73.04	74.58	1.54
GM-4I	7, 9, 2	70.42	72.13	1.71
GM-5S	10, 10, 1	70.04	70.45	0.41
GM-5I	10, 10, 2	69.68	70.32	0.64
GM-6S	11, 21, 1	*69.70*	69.77	0.07
GM-6I (2)	*11, 21, 2*	*64.39*	*69.67*	*5.28*
GM-7S	13, 27, 1	70.56	71.25	0.69
GM-7I	13, 27, 2	70.36	71.04	0.68
GM-7D	13, 27, 3	67.84	70.55	2.71
GM-8S	15, 37, 1	*74.71*	76.83	2.12
GM-8I	15, 37, 2	73.64	75.48	1.84
GM-9S	13, 9, 1	69.17	70.09	0.92
GM-9I	13, 9, 2	69.05	69.89	0.84
GM-10S	20, 7, 1	68.62	69.70	1.08
GM-10I	21, 6, 2	68.31	68.56	0.25
GM-12S	29, 15, 1	68.60	68.65	0.05
GM-12I	29, 15, 2	68.04	68.60	0.56
GM-13S	31, 23, 1	68.88	69.42	0.54
GM13I	32, 23, 2	68.97	68.92	-0.05
GM-13D	34, 22, 3	66.67	68.29	1.62
GM-14S	32, 28, 1	67.59	69.47	1.88
GM-14I	36, 25, 2	67.60	68.17	0.57
GM-15S	41, 38, 1	72.25	72.73	0.48
GM-15I	48, 40, 2	64.46	65.94	1.48
GM-16S	36, 16, 1	68.27	67.94	-0.33
GM-16I	36, 16, 2	68.20	67.88	-0.32
GM-17S (2)	*38, 9, 1*	*73.42*	*69.90*	*-3.52*
GM-18S	45, 11, 1	65.64	66.63	0.99
GM-18I	44, 11, 2	66.47	66.60	0.13
GM-19S	48, 33, 1	65.63	66.56	0.93
GM-19I	48, 33, 2	65.56	66.39	0.83
GM-20S	51, 16, 1	66.78	66.21	-0.57
GM-20I	51, 16, 2	66.13	65.80	-0.33
GM-20D	51, 16, 3	64.33	65.26	0.93
GM-21S	51, 23, 1	65.79	67.37	1.58
GM-21I	51, 23, 2	65.24	66.56	1.32
GM-22S	51, 30, 1	65.73	66.52	0.79
GM-22I	51, 30, 2	64.59	65.98	1.39
GM-23S	29, 8, 1	67.98	67.68	-0.30
GM-23I	29, 8, 2	67.90	67.62	-0.28

TABLE 7-3
MODEL VALIDATION RESULTS
JULY 24, 1992 PUMPING CONDITIONS

WELL	GRID LOCATION (R,C,L)	JULY 24, 1992 WATER ELEVATION	MODELED WATER ELEVATION	MODELED - MEASURED (FT)
HN-8D (2)	*17, 37, 3*	*70.88*	*74.87*	*3.99*
HN-24S	13, 22, 1	69.32	69.71	0.39
HN-24I	13, 22, 2	67.80	69.57	1.77
HN-25S	16, 21, 1	69.83	69.28	-0.55
HN-25I	16+17, 21+22, 2	69.26	69.20	-0.06
HN-25D	16, 21, 3	66.49	68.34	1.85
HN-26S	18, 26, 1	72.91	72.48	-0.43
HN-26I	19, 26, 2	71.47	72.03	0.56
HN-27S	22+23, 30, 1	77.70	76.91	-0.79
HN-27I	22+23, 30, 2	Destroyed	--	--
HN-28S	26+27, 29+30, 1	71.97	72.66	0.69
HN-28I	26+27, 29+30, 2	69.86	72.26	2.40
HN-29S	26+27, 26+27, 1	71.13	71.32	0.19
HN-29I	26+27, 26+27, 2	69.27	71.08	1.81
HN-29D (2)	*26+27, 26+27, 3*	*66.88*	*70.59*	*3.71*
HN-30S	22, 36+37, 1	80.64	82.40	1.76
HN-30I (2)	*22, 36+37, 2*	*74.84*	*78.82*	*3.98*

Note: calibration criterial +/- 2.0 ft.
(1) Monitoring well not included in validation due to proximity to production well.
(2) Monitoring well not included in validation due to proximity to recharge basin.

MEAN ERROR:	0.75
ABSOLUTE RESIDUAL VALUE:	48.64
MODFLOW WATER BALANCE ERROR:	-0.04%

Figure 7-1
Model vs. Measured Values, Jan. 1992

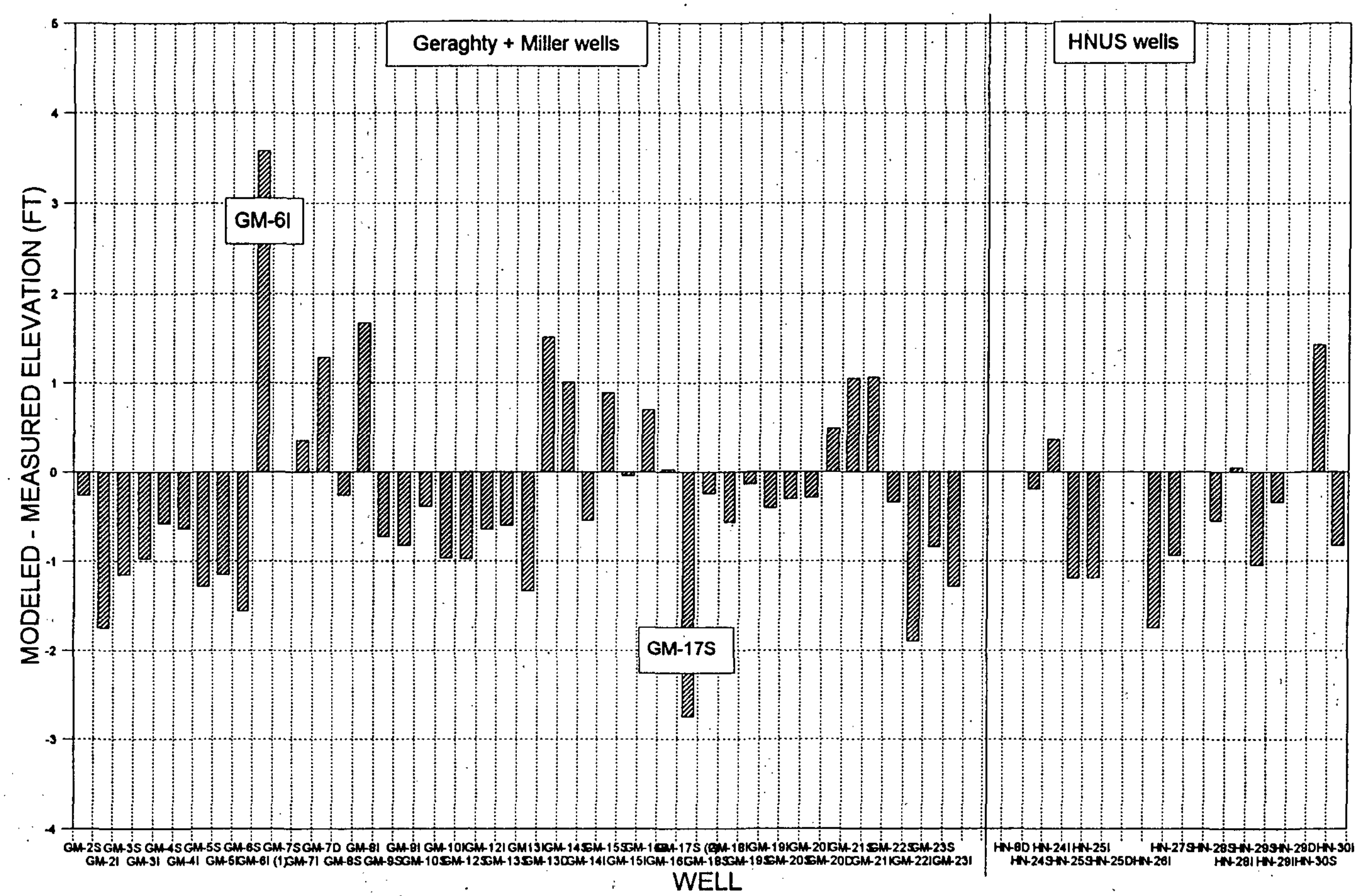
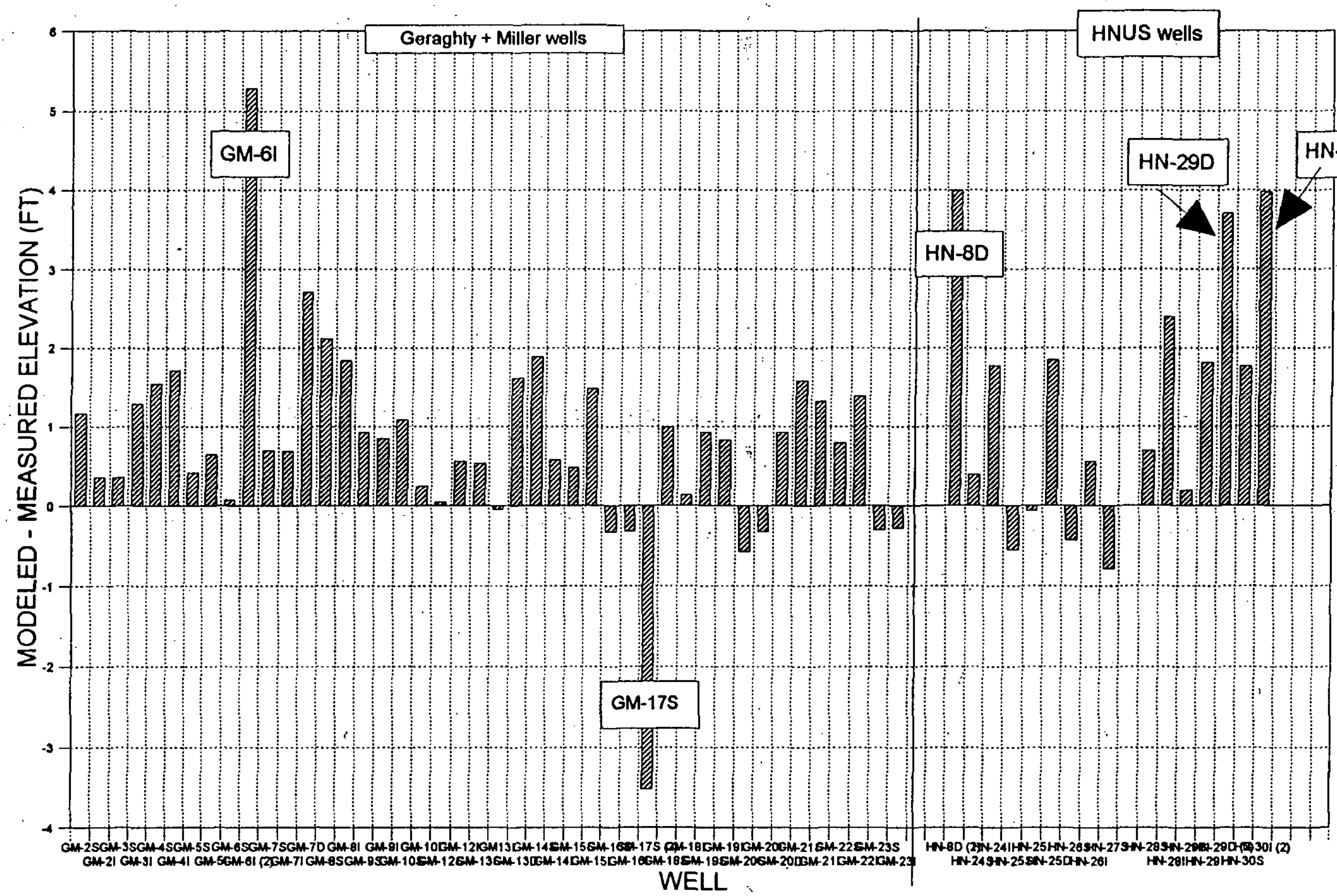


Figure 7-2
Model vs. Measured Values, July, 1992



validation, because if changes were made to the model constant head elevations the run would be considered to be a calibration run rather than a validation run. This disparity between the natural system and the modeled system may account for the generally low modeled vs. measured results in the January 1992 validation run (-0.41 ft mean error) and the generally high modeled vs. measured results in the July 1992 validation run (0.75 ft mean error). Apparently, natural boundary conditions were higher in the January 1992 run, which used February boundary conditions, while the natural boundary conditions were lower for the July validation run, which used August boundary conditions. The consistently low modeled results across the site in the January 1992 simulation and the consistently high model results across the site in the July 1992 simulation suggest that these differences may be due to constant head elevations rather than errors in the hydraulic conductivity or other model parameters. All aquifer parameters were constant at calibration values during the two validation runs. If the consistently high and low modeled values were due to errors in aquifer parameters (such as hydraulic conductivities, or recharge), the modeled to measured differences would show specific high or low modeled values in all simulations rather than the pattern seen in validation.

8.0 PARTICLE TRACKING

MODPATH, a module of MODFLOW, was used to track the locations of particles after simulated releases of contaminants from suspected source areas. Particle tracking was performed to determine the possible directions and rates that contaminants will move after a release. Several particle tracking scenarios were performed, each under a different pumping condition of Grumman production wells and recharge basins, and with different BWPD well pumping rates. MODPATH utilizes the groundwater flow data generated by MODFLOW and simulates advective transport of particles. Other contaminant transport parameters, such as diffusion, dispersion, contaminant half-life, are not considered in the MODPATH simulations. All MODPATH simulations were performed using the aquifer parameters determined during model calibration for pumping scenarios run to a steady-state.

Particle tracking analysis is used to trace flow paths, expressed as lines, by tracking the movement of infinitely small imaginary particles placed in the flow field. This process may also be used to determine the capture zone of a well by releasing particles in a grid block, generally a well, and tracking the particles in reverse along pathlines to determine their source.

8.1 PARTICLE RELEASE LOCATIONS

For each pumping configuration, particle tracking analysis was performed for three separate release locations. Particles were released from possible contaminant sources at Site 1 and the northern Grumman recharge basins. For these two sites particle tracking was performed in the forward direction to determine where particles would move with time. Particles were also released at the eastern BWD wells (BP-07, BP-08 and BP-09) and particle tracking was performed in reverse to determine the capture zones of these wells under the various pumping conditions. For all particle tracking simulations, recharge was applied to the top layer of the model; particles were not influenced by weak sinks; and, particles were not placed in constant head nodes.

8.1.1 Site 1

The particle release location of Site 1 is shown in Figure 8-1. Particles were released from four grid blocks with two particles being released from each face of each block. Twelve particles were released from each grid block with a total of 48 particles released from Site 1.

8.1.2 NWIRP Basins

The particle release locations of the NWIRP recharge basins are shown in Figure 8-1. Particles were released from 16 grid blocks with one particle being released from each face of each block. Six particles were released from each grid block with a total of 96 particles released from the north recharge basins.

8.1.3 BWD Wells

Particles were released from each of the three BWD wells to the east of the NWIRP. The location of these wells is shown in Figure 6-6. Four particles were released from each face with 24 particles released from each well. These particles were backwards tracked to determine where they originated in order to define the capture zone of each well.

8.2 PUMPING SCENARIOS

Several pumping scenarios were considered for particle tracking simulations. These pumping scenarios were based on past, current, and future potential pumping configurations at the Grumman production wells, Grumman recharge basins, and BWD wells. The emphasis of these simulations was to determine where particles will move after a release from potential contaminant sources and what effect, if any, these potential contaminant sources will have on BWD wells.

The results of the MODPATH particle tracking analysis are presented as water table maps which reflect the modeled water elevation in layer 1, with the particle tracks overlaid. Presenting both particle tracks and the water table allows for the inspection of the particle trackways, and the geometry of the water table, which is controlled by the wells and basins which are active during each pumping scenario.

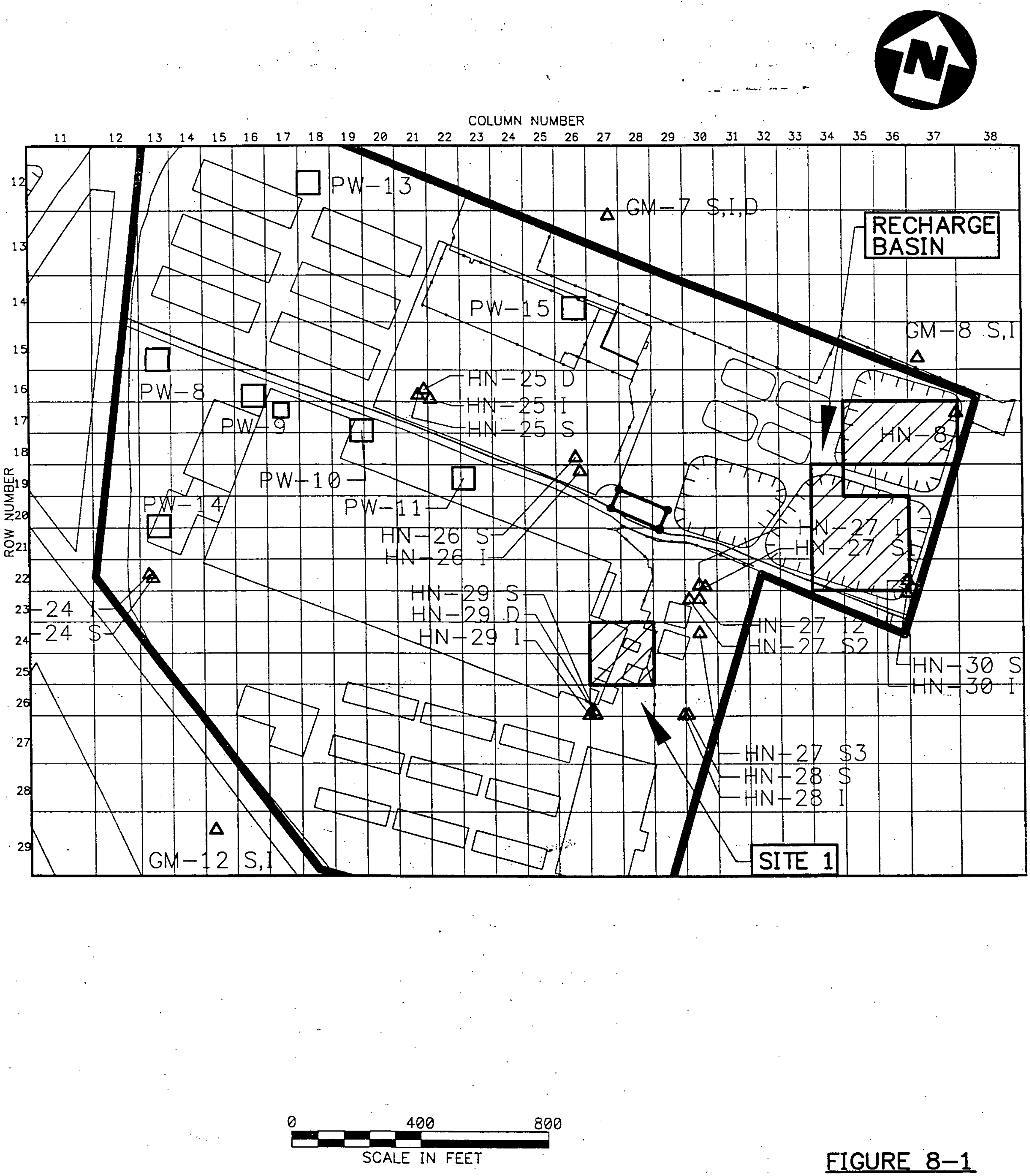


FIGURE 8-1

PARTICLE RELEASE LOCATIONS
SITE 1 AND RECHARGE BASIN
BETHPAGE NWIRP

HALLIBURTON NUS
Environmental Corporation

8.2.1 Current Conditions

Current conditions were simulated in order to determine where contaminants may be moving under current pumping conditions. Production well pumping rates for current conditions at the Grumman site were determined from 1991 and 1992 average pumping rate data. The yearly average was determined for each Grumman production well, and pumping rates used in the scenarios for these wells are listed in Table 8-1. All water removed from the pumping wells north of the LIRR tracks was recharged to northern recharge basins, and water removed from the south Grumman production wells was recharged to the south Grumman recharge basins.

BWD wells production rate data was determined from 1991 and 1992 average pumping rate data, and pumping values used in the scenarios are shown on Table 8-2. The BWD wells were considered to be pumping at 120% of 1991 and 1992 rates, and well BP-09 was considered to be active despite it being taken off-line in 1991. These assumptions represent conservative estimates of the current conditions at the BWD wells. Three recharge basins were considered to be active on Hooker-Ruco property, pumping at 202 gpm per basin, a rate determined during model calibration. In all of the pumping conditions water pumped from the BWD well was considered to be removed from the flow system. The northern and southern constant head elevations were averages of the February and August conditions.

The particle tracking results for current pumping conditions are illustrated in Figures 8-2 through 8-4. Table 8-3 summarizes starting location and final location results of the particle tracking analysis, and the maximum and minimum travel times for all pumping conditions. Results of the particle tracking are listed below:

- All particles released from Site 1 under current pumping conditions are captured by PW-01,
- Particles released from the recharge basins show that 30% of particles released are captured to Grumman production wells PW-01, PW-09, PW-10, PW-1, PW-15 and PW-16. The remaining 70% of the particles flow to the south constant head boundary. No particles from the north recharge basins are captured by BWD wells BP-10 or BP-11, and,
- The capture zone for BWD wells BP-07, BP-08 and BP-09 extends into the northern constant head boundary.

TABLE 8-1
AVERAGE GRUMMAN PRODUCTION WELL PUMPING RATES FOR OCTOBER 1991 THROUGH SEPTEMBER 1992

PRODUCTION WELL	LOCATION (ROW,COL.)	LAYER	% PUMPED FROM LAYER	1991/1992 AVERAGE PUMPING RATE (1) (gal./day)	(gpm)	HIGH PUMPING CONDITIONS (gal./day)	(gpm)
SOUTH PRODUCTION WELLS							
PW-1	42, 10	5	100%	1,497,655	1,040	1,296,000	900
PW-2	34, 11	5	100%	132	0.092	1,296,000	900
PW-3	38, 9	5	100%	105,441	73	1,296,000	900
PW-4	39, 11	4	100%	211	0.147	1,296,000	900
PW-5	31, 9	4	100%	285	0.198	1,296,000	900
PW-6	27, 7	3	11%	47,760	33	142,560	99
		4	89%	386,418	268	1,153,440	801
SOUTH PRODUCTION WELL TOTALS:				2,037,902	1,415	7,776,000	5,400
SOUTH RECHARGE BASINS - OUTFALLS 005, 006 AND 007							
23 GRID BLOCKS (2	--	1	100%	88,604	62	338,087	235
NORTH PRODUCTION WELLS							
PW-8	15, 13	4	16%	770	1	207,360	144
		5	84%	4,040	3	1,088,640	756
PW-9	16, 16	4	100%	716,967	498	1,296,000	900
PW-10	18, 19	4	100%	790,707	549	1,296,000	900
PW-11	19, 23	4	37%	149,128	104	479,520	333
		5	63%	253,921	176	816,480	567
PW-13	12, 18	5	100%	702,770	488	1,296,000	900
PW-14	21, 13	4	62%	170	0.118	803,520	558
		5	38%	104	0.072	492,480	342
PW-15	14, 26	5	100%	318,482	221	1,296,000	900
PW-16	9, 31	4	100%	1,173,992	815	1,296,000	900
NORTH PW TOTAL:				4,111,051	2,855	10,368,000	7,200
NORTH RECHARGE BASINS - OUTFALLS 004 AND 010							
24 GRID BLOCKS (2	--	1	100%	171,294	119	432,000	300

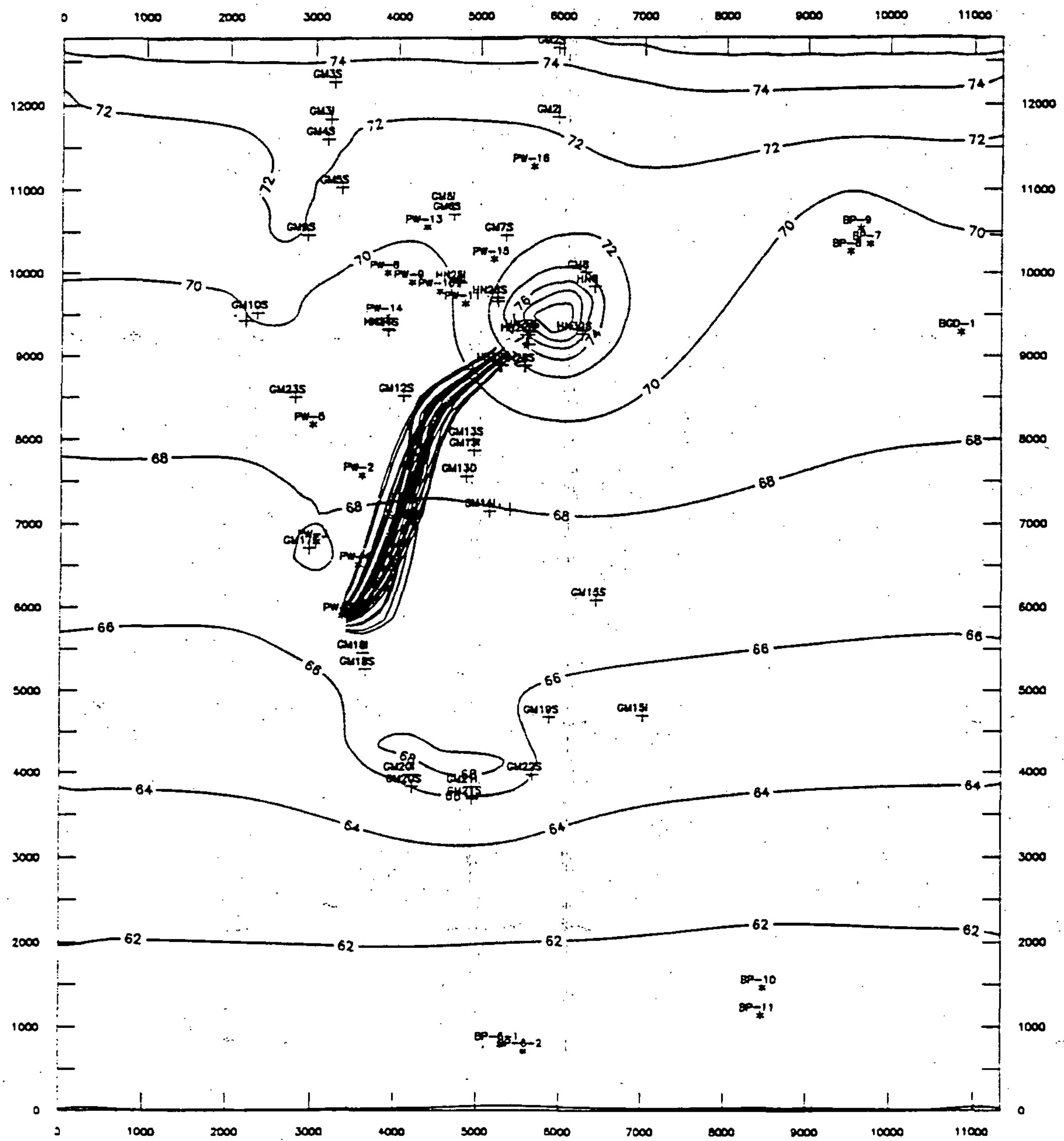
(1) Monthly pumping rates from Grumman Aerospace data.
(2) Calculations are totals for each basin grid block.

TABLE 8-2
AVERAGE AND HIGH PUMPING RATES FOR BWD WELLS

WELL NUMBER	NYS DEC NUMBER	GRID LOCATION (R,C,L,)	TOTAL DEPTH (ft)	SCREEN INTERVAL (fbgs)	CURRENT CONDITIONS (1) (mgpd)	CURRENT CONDITIONS (1) (gpm)	HIGH PUMPING CONDITIONS (2) (mgpd)	HIGH PUMPING CONDITIONS (2) (gpm)
North Wells								
7	8767	13, 49, 5	655	590 to 656	0.96	667	1.76	1,222
8	8768	14, 49, 5	682	617 to 677	1.24	861	1.66	1,153
9	6078	12, 49, 3	280	225 to 275	1.24 (3)	861 (3)	1.76	1,222
BGD-1	9591	22, 52, 5	607	542 to 602	0.05	35	1.73	1,201
South Wells								
10	6915	59, 46, 5	608	540 to 603	0.60	417	2.00	1,389
11	6916	60, 46, 5	611	556 to 606	0.32	222	1.76	1,222
5	8004	Off Grid (4)	740	675 to 735	0.32	222	1.77	1,229
6-1	3876	61, 27, 4	386	321 to 381	0.50	347	1.84	1,278
6-2	8941	61, 30, 5	775	710 to 770	0.37	257	1.70	1,181

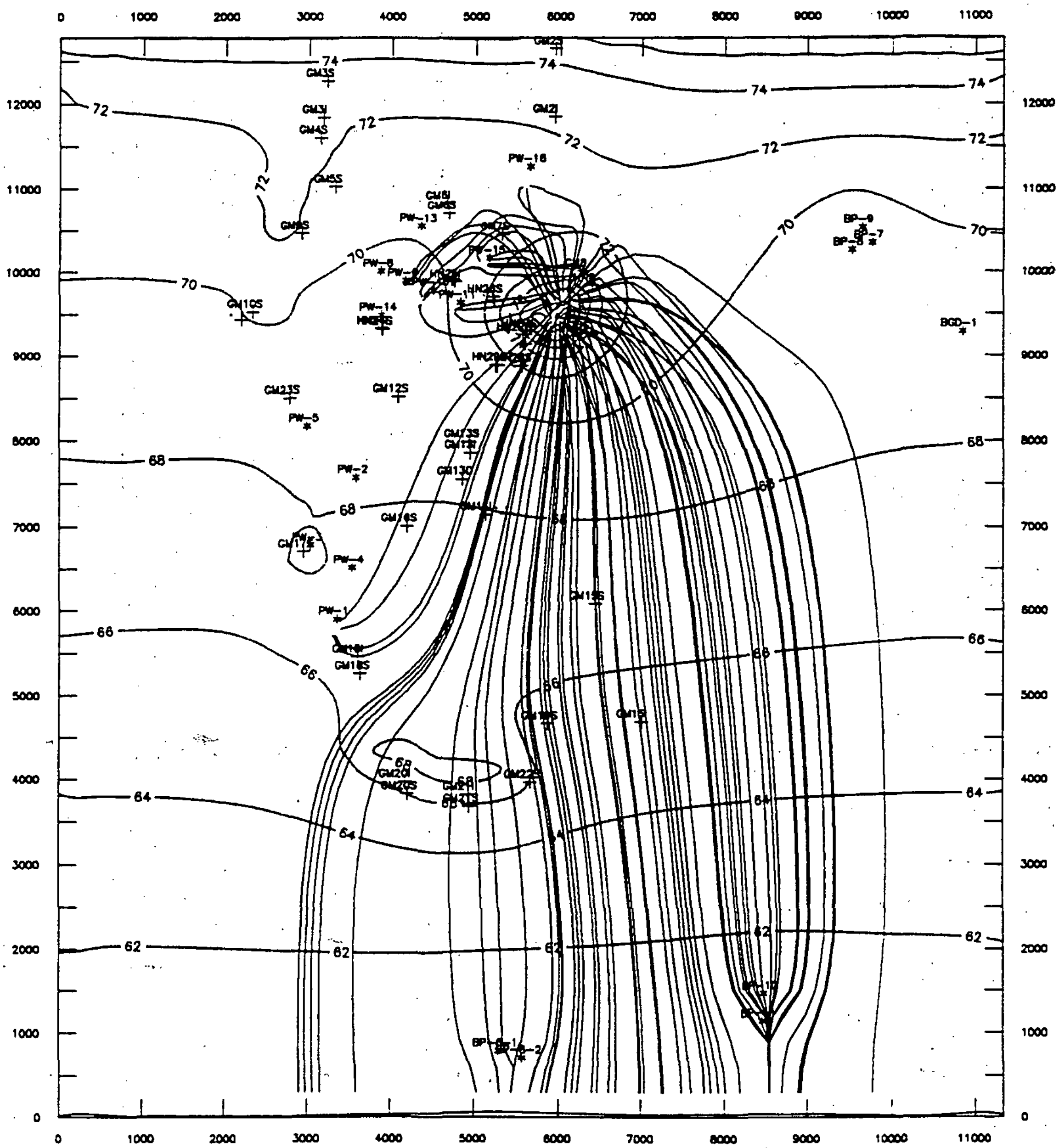
(1) Data is 120% of 1991 average pumping rate (from1991 Bethpage Water District Annual Operations Report).
(2) Actual Capacity of Wells.
(3) Well 9 assumed to be pumping at same rate as well 8, although well was not pumping in 1991.
(4) Well BP-05 is located off of the model grid. Pumping rates are given for comparison to other BWD wells.
fbgs = feet below ground surface.
mgpd = millions of gallons per day.

Figure 8-2
Particle Tracking Results - Site 1 Release - Current Conditions.



• = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 8-3
Particle Tracking Results - NWIRP Basin Release - Current Conditions.



* = Production Well Location
\+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 8-4
Particle Tracking Results - Capture Zones of BWD Wells - Current Conditions.

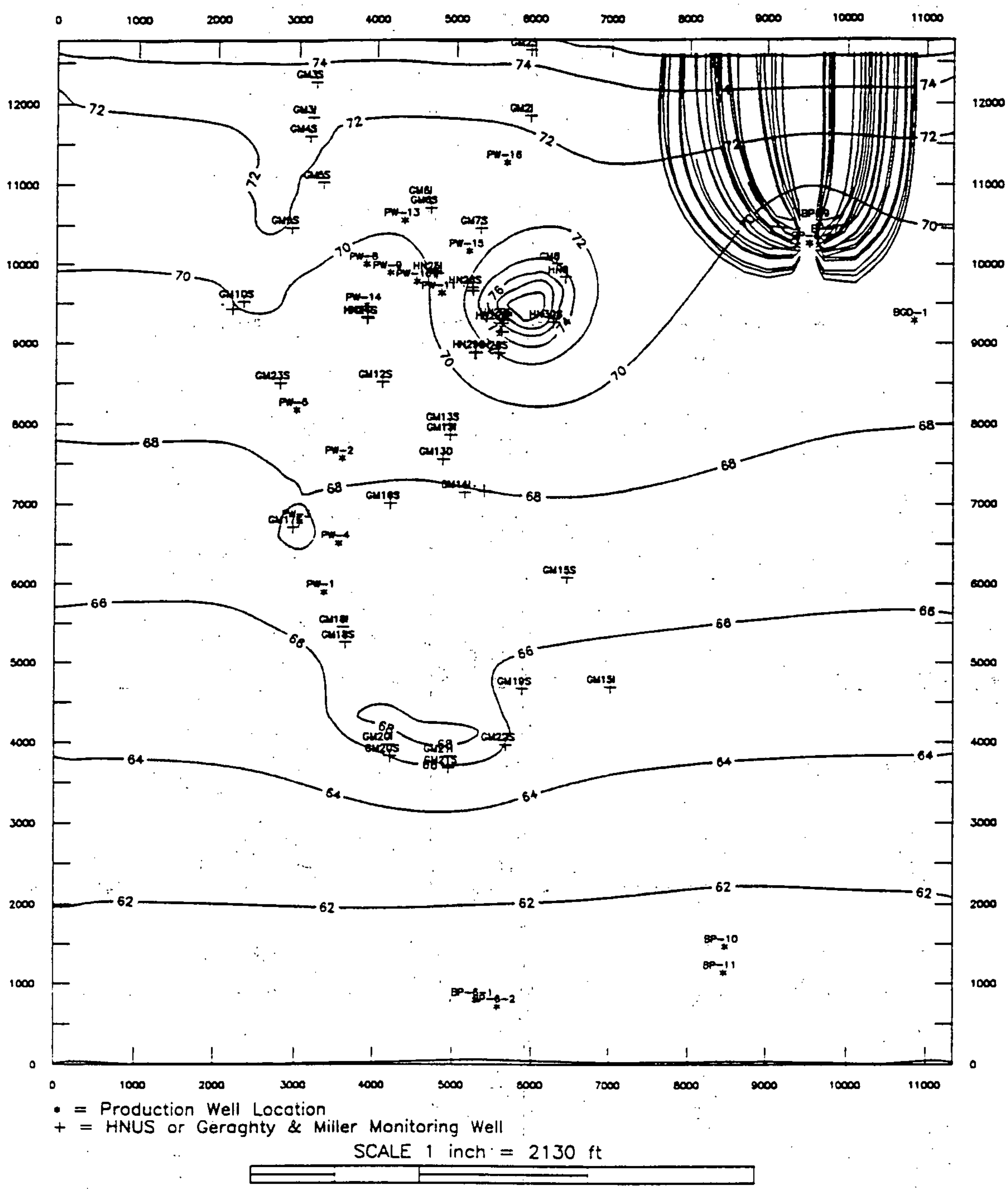


TABLE 8-3
SUMMARY OF PARTICLE TRACKING RESULTS AND TRAVEL TIMES

Grumman Pumping Conditions	BWD Pumping Conditions	Particle Release Location	Number of Particles Released	Percentage of Particles Reaching Each Location					
				Grumman PW's / Basins	Min./Max. Travel Time (yrs.)	Constant Head Boundary	Min./Max. Travel Time (yrs.)	BWD Wells	Min./Max. Travel Time (yrs.)
Current Conditions	Current Conditions	Site 1	48	100 %	14.8 / 53.5	0%	0	0%	0
		Recharge Basins	96	30%	2.4 / 13.8	70%	20.4 / 55.5	0%	0
		BWD Wells (1)	72	0%	--	100%	1.7 / 21.6	--	--
High	Average	Site 1	48	100%	3.8 / 11.8	0%	--	0%	0
		Recharge Basins	96	73%	0.8 / 40.4	24%	20.7 / 58.2	3%	10.4 / 24.1
		BWD Wells (1)	72	7%	7.4 / 18.6	93%	1.6 / 34.9	--	--
High	High	Site 1	48	100%	4.0 / 11.6	0%	0	0%	0
		Recharge Basins	96	65%	0.8 / 30.3	2%	30.9 / 69.9	33%	7.4 / 49.5
		BWD Wells (1)	72	8%	7.11 / 15.4	92%	1.2 / 26.6	--	--
No Pumping	Average	Site 1	48	0%	0	100%	49.7 / 58.5	0%	0
		Recharge Basins (2)	0	--	--	--	--	--	--
		BWD Wells (1)	72	0%	0	100%	2.8 / 18.8	--	--
No Pumping	High	Site 1	48	0%	0	0%	0	100%	48.8 / 58.0
		Recharge Basins (2)	0	--	--	--	--	--	--
		BWD Wells (1)	72	0%	0	100%	1.7 / 30.9	--	--

(1) Capture zone analysis performed for BWD wells.
(2) Recharge basins inactive during No Pumping conditions.

8.2.2 High Pumping Conditions

High pumping conditions were simulated to determine where particles may have moved from contaminant sources during past pumping conditions. Before 1985 additional pumping/recharge activity at the Grumman production wells and recharge basins may have occurred due to the increased manufacturing activity at the facility. High pumping conditions at Grumman were simulated by pumping all 14 production wells at 75% of maximum capacity, as listed in Table 8-1. All water pumped by Grumman production wells was returned to the recharge basins. Three recharge basins were considered to be active on Hooker-Ruco property, recharging at 202 gpm per basin (this rate was determined during model calibration). The northern and south constant head elevations were averages of the February and August 1992 conditions. Two separate scenarios were considered for past pumping conditions at the BWD wells, as described below.

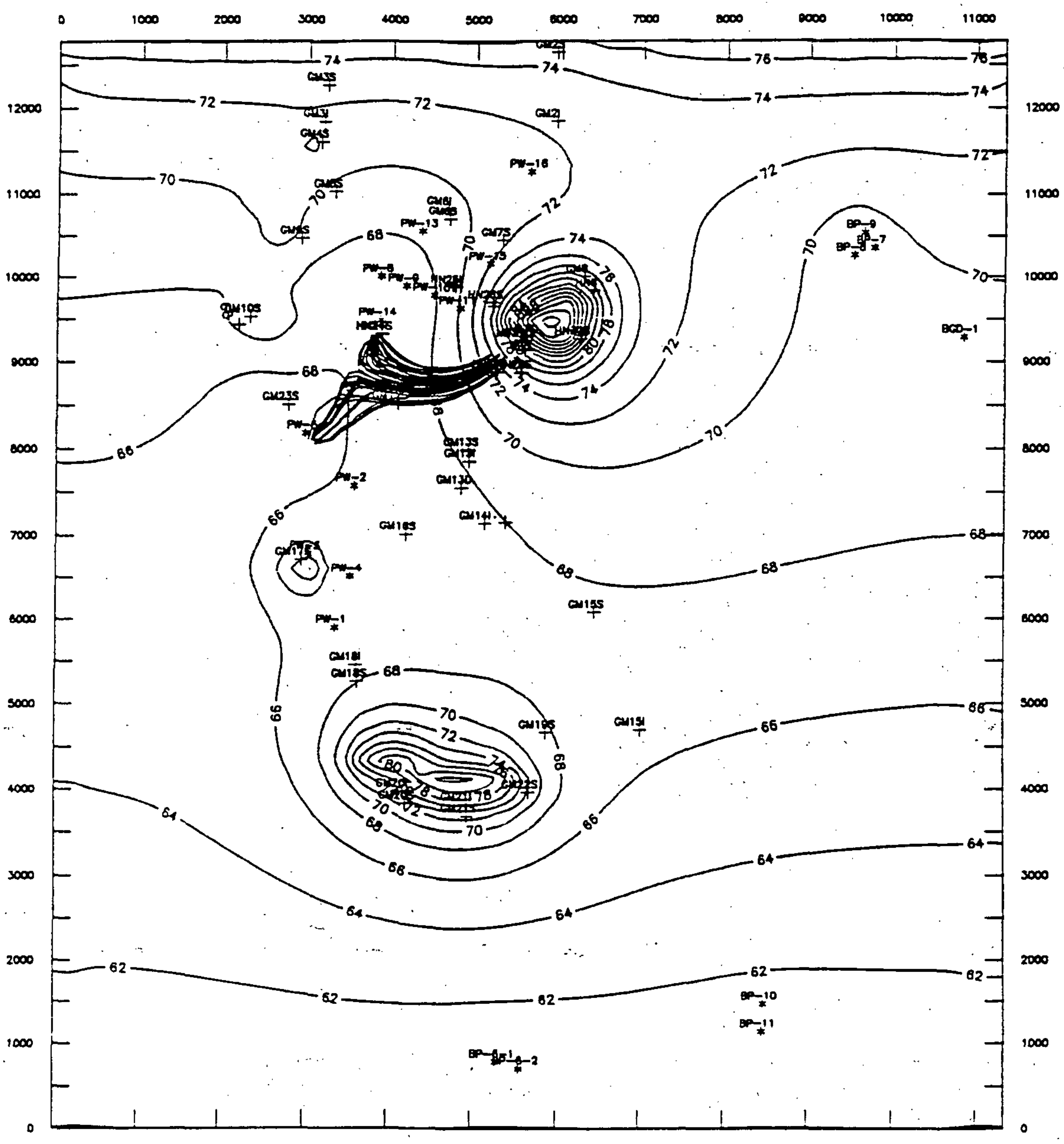
8.2.2.1 Average BWD Well Pumping Conditions

Average BWD well pumping conditions were simulated by pumping at the rate determined from 1991 and 1992 average pumping rate data. Pumping values used in the scenarios are shown on Table 8-2. The BWD wells were considered to be pumping at 120% of 1991 and 1992 rates, and well BP-09 was considered to be active despite it being taken off-line in 1991. These assumptions represent conservative estimates of the current conditions at the BWD wells.

The particle tracks for high Grumman pumping and average BWD pumping conditions are illustrated in Figures 8-5 through 8-7. Results of the particle tracking are listed below:

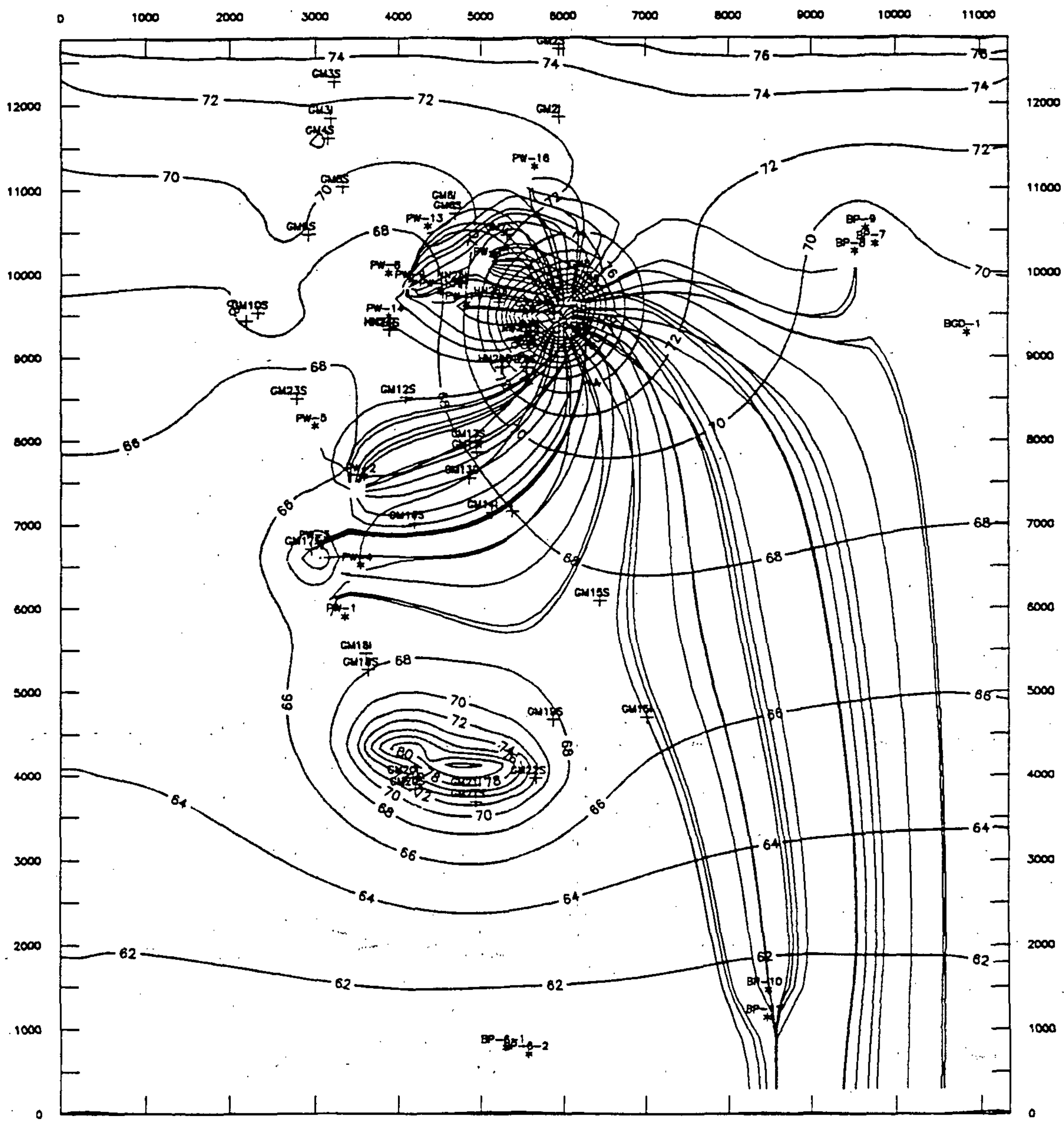
- All particles released from Site 1 are captured by PW-14 and PW-05,
- 73% of particles released from the recharge basins are captured by the Grumman production wells, 24% reach the south constant head boundary, while 3% of particles reach BP-08 from the NWIRP recharge basins, and,
- The capture zones for BWD wells BP-07, BP-08 and BP-09 extend primarily into the northern constant head boundary. Some particles originate in the vicinity of the NWIRP recharge basins. Three particles (4% of total) move from the north recharge basins to BP-08, while two particles

Figure 8-5
Particle Tracking Results - Site 1 Release - Grumman at High Pumping Conditions, BWD at Average Pumping Conditions.



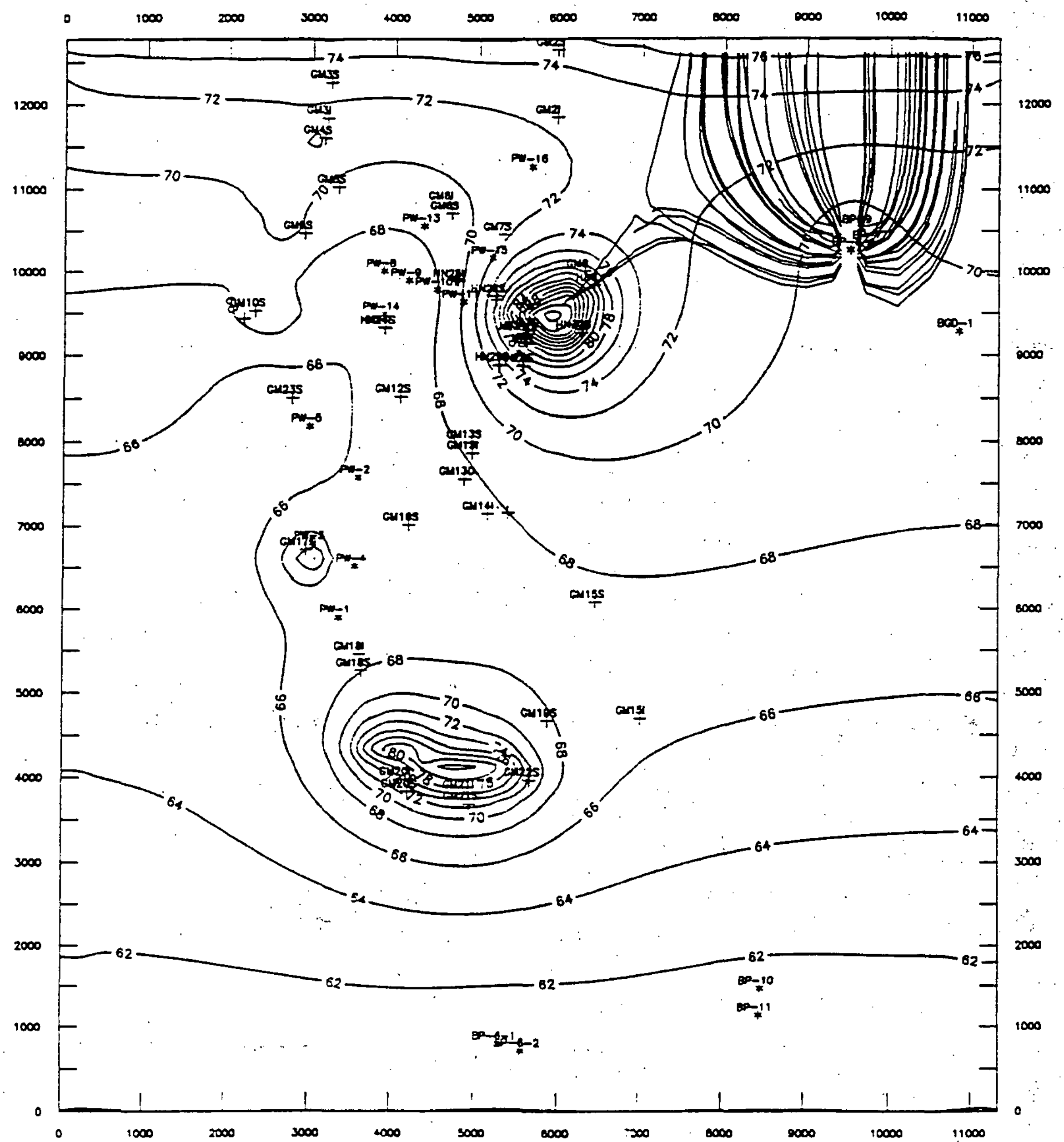
* = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 8-6
Particle Tracking Results - NWIRP Basin - Grumman at High Pumping Conditions, BWD at Average Pumping Conditions.



* = Production Well Location
\+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 8-7
Particle Tracking Results - Capture Zones of BWD Wells - Grumman at High Pumping Conditions, BWD at Average Pumping Conditions.



• = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

(3% of total) move from northwest of the recharge basins to BP-09.

8.2.2.2 High BWD Well Pumping Conditions

This pumping condition was simulated to determine were particles may have moved under past pumping conditions. These high pumping conditions may not have occurred in the past for extended periods of time, as assumed in the model run. However, these situations may represent end-member flow conditions which affected groundwater flow at the site. In this scenario all BWD wells were pumping at their actual (highest) capacity.

The particle tracks for high Grumman pumping and high BWD pumping conditions are illustrated in Figures 8-8 through 8-10. Results of the particle tracking are listed below:

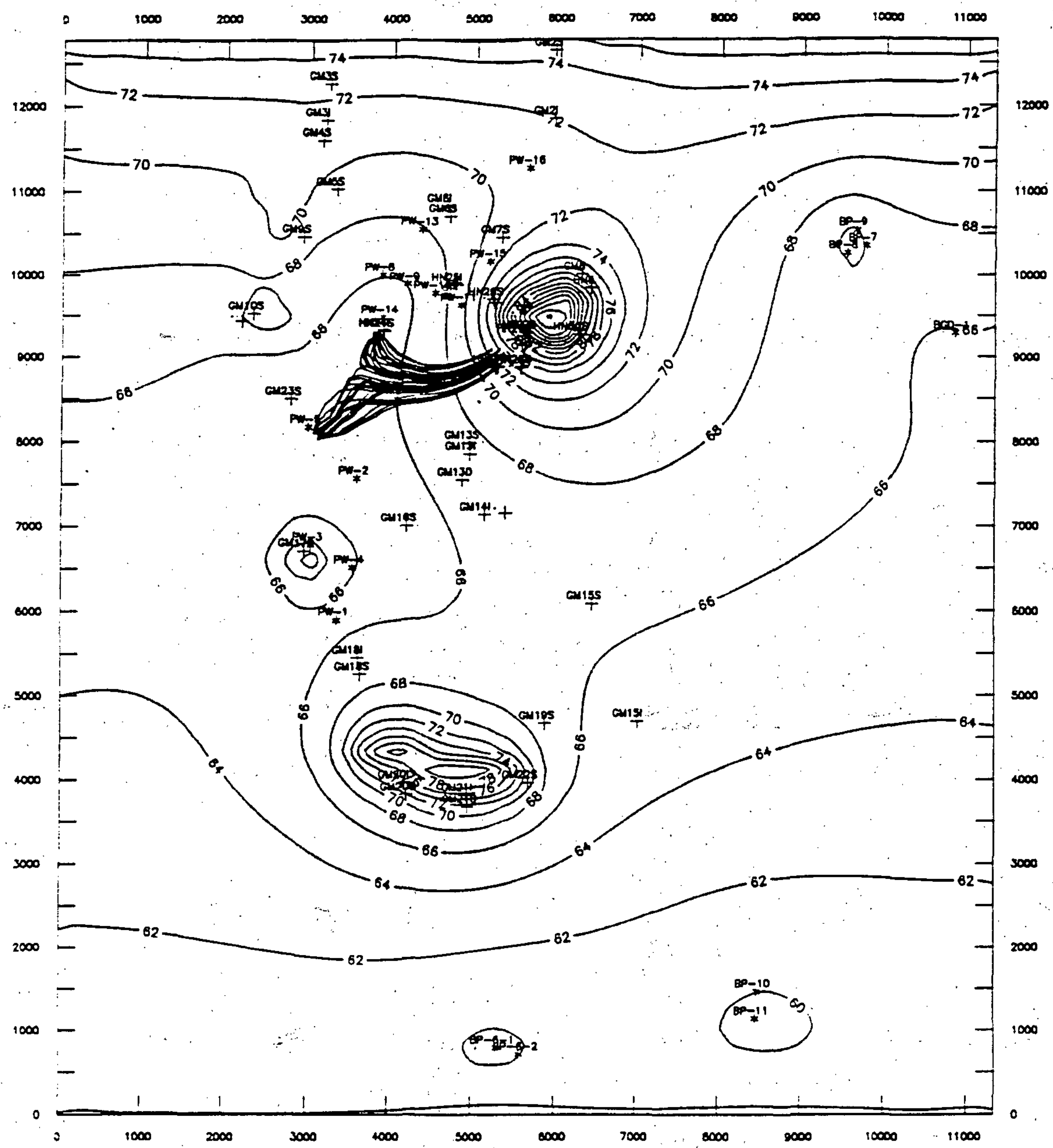
- All particle released from Site 1 are captured by PW-14 and PW-05,
- 65% of particles released from the recharge basins are captured by Grumman production wells with 2% reaching the south constant head boundary. BWD well BP-11 receives 19%, BGD-1 receives 7%, BP-08 receives 6% and BP-09 receives 1% of the total particles released,
- The capture zones for BWD wells BP-07, BP-08, and BP-09 extend primarily into the northern constant head boundary, although 8% of particles move from the NWIRP recharge basins to BP-08.

8.2.3 No Pumping Conditions

No pumping conditions were simulated to determine how contaminants would move if Grumman production wells and recharge basins were inactive and no pumping activity was occurring at the Grumman site. These conditions may have occurred during the past, during holidays or during periods of slow production. All Grumman production wells and recharge basins were considered to be inactive. Recharge basins at Hooker-Ruco were considered inactive. As with all pumping scenarios, the northern and southern constant head elevations were averages of the February and August 1992 conditions.

Two separate scenarios were considered for past pumping conditions at the BWD wells, as described

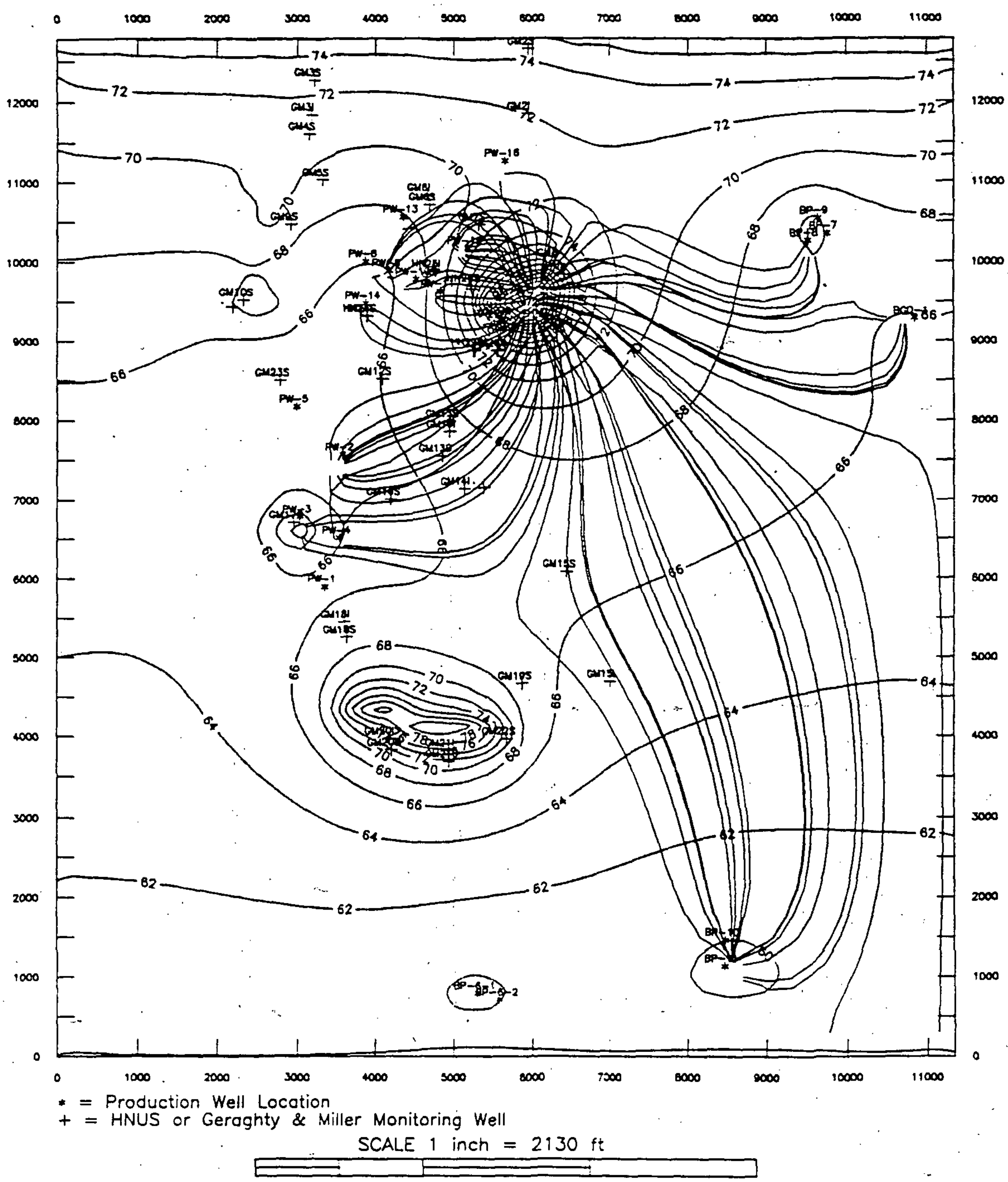
Figure 8-8
Particle Tracking Results - Site 1 Release - Grumman at High Pumping Conditions, BWD at High Pumping Conditions.



* = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 8-9

Particle Tracking Results - NWIRP Basin - Grumman at High Pumping Conditions, BWD at High Pumping Conditions.

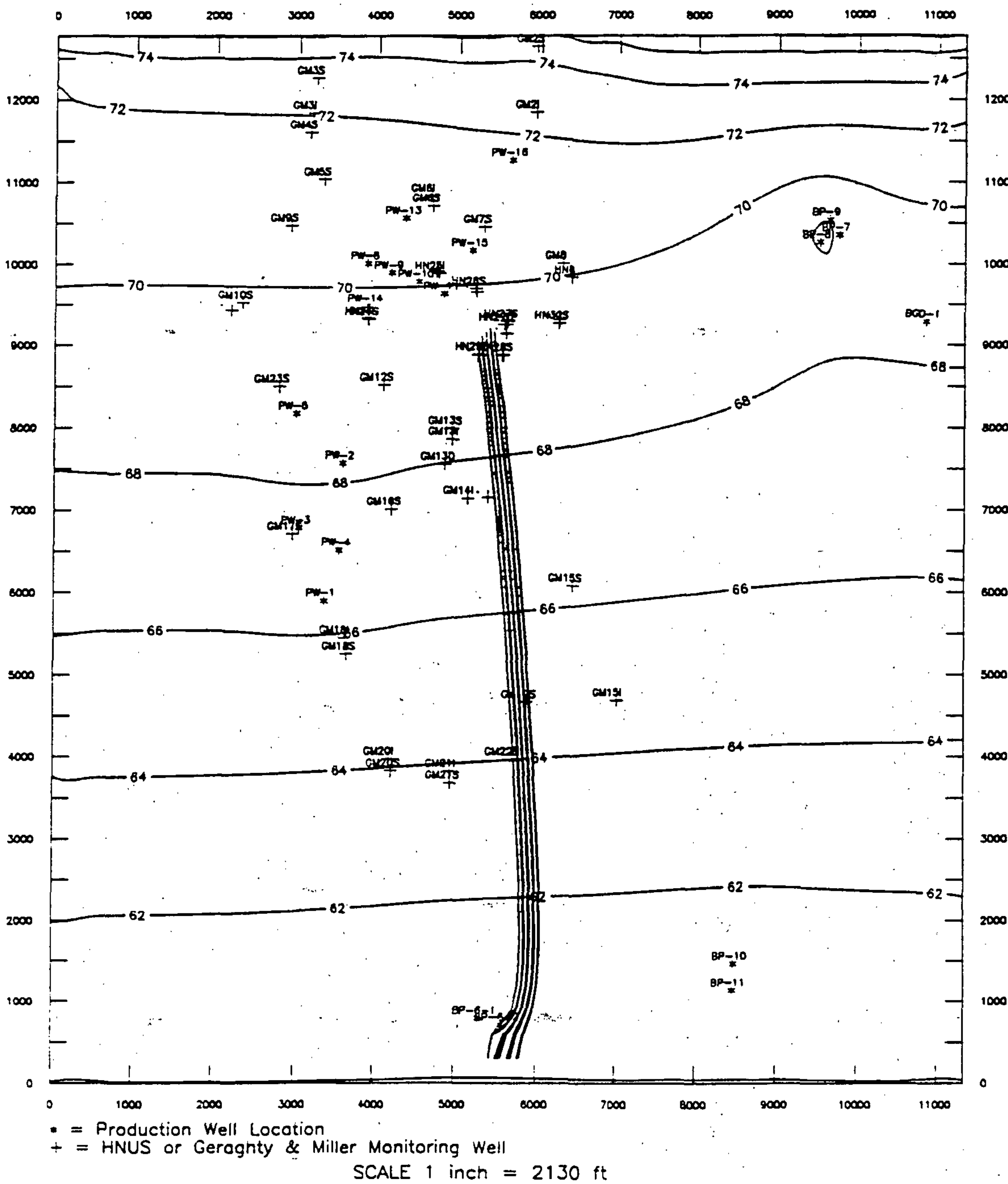


* = Production Well Location

+ = HNUS or Geraghty & Miller Monitoring Well

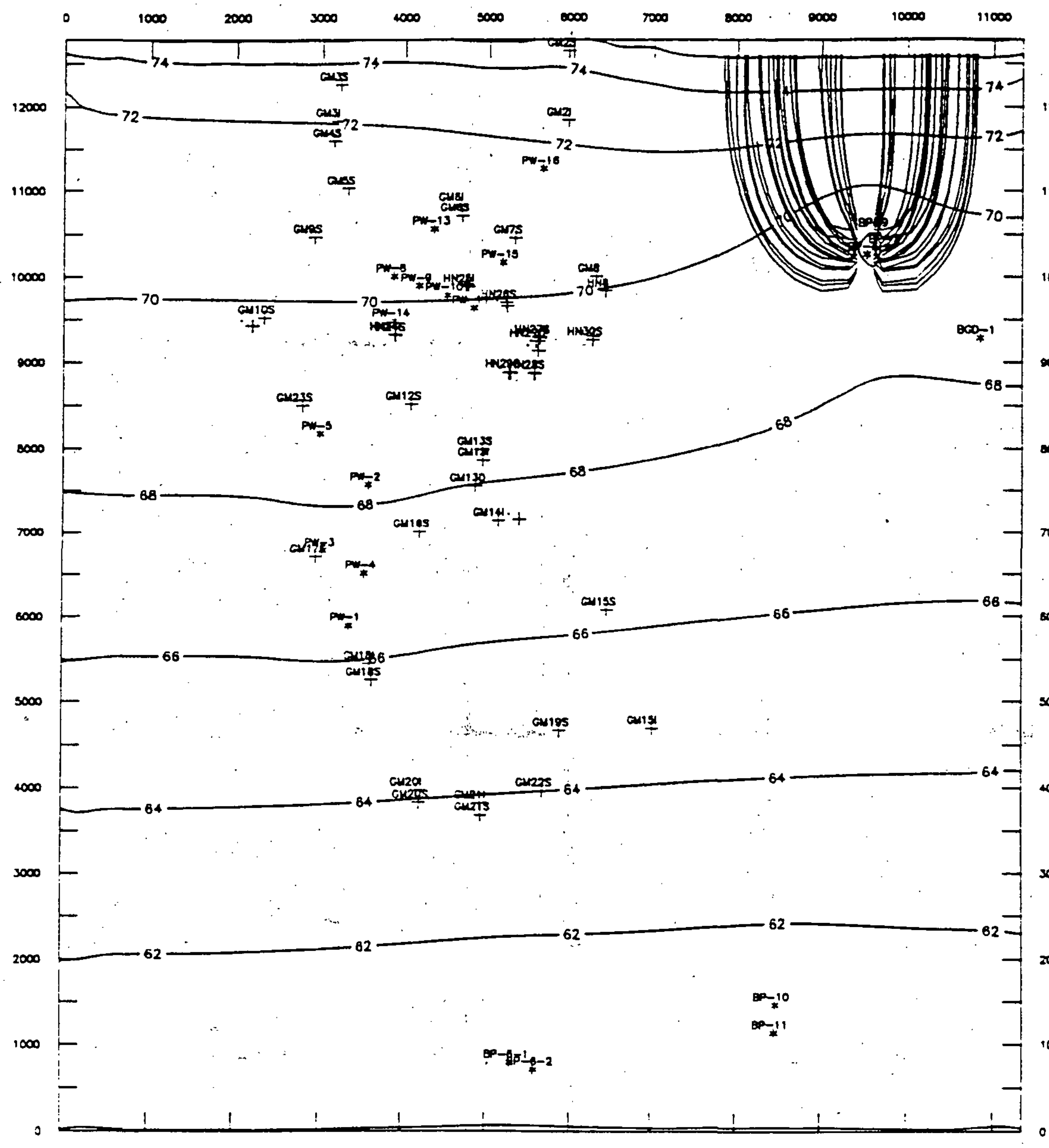
SCALE 1 inch = 2130 ft

Figure 8-11
Particle Tracking Results - Site 1 Release - No Pumping at Grumman, BWD at Average Pumping Conditions.



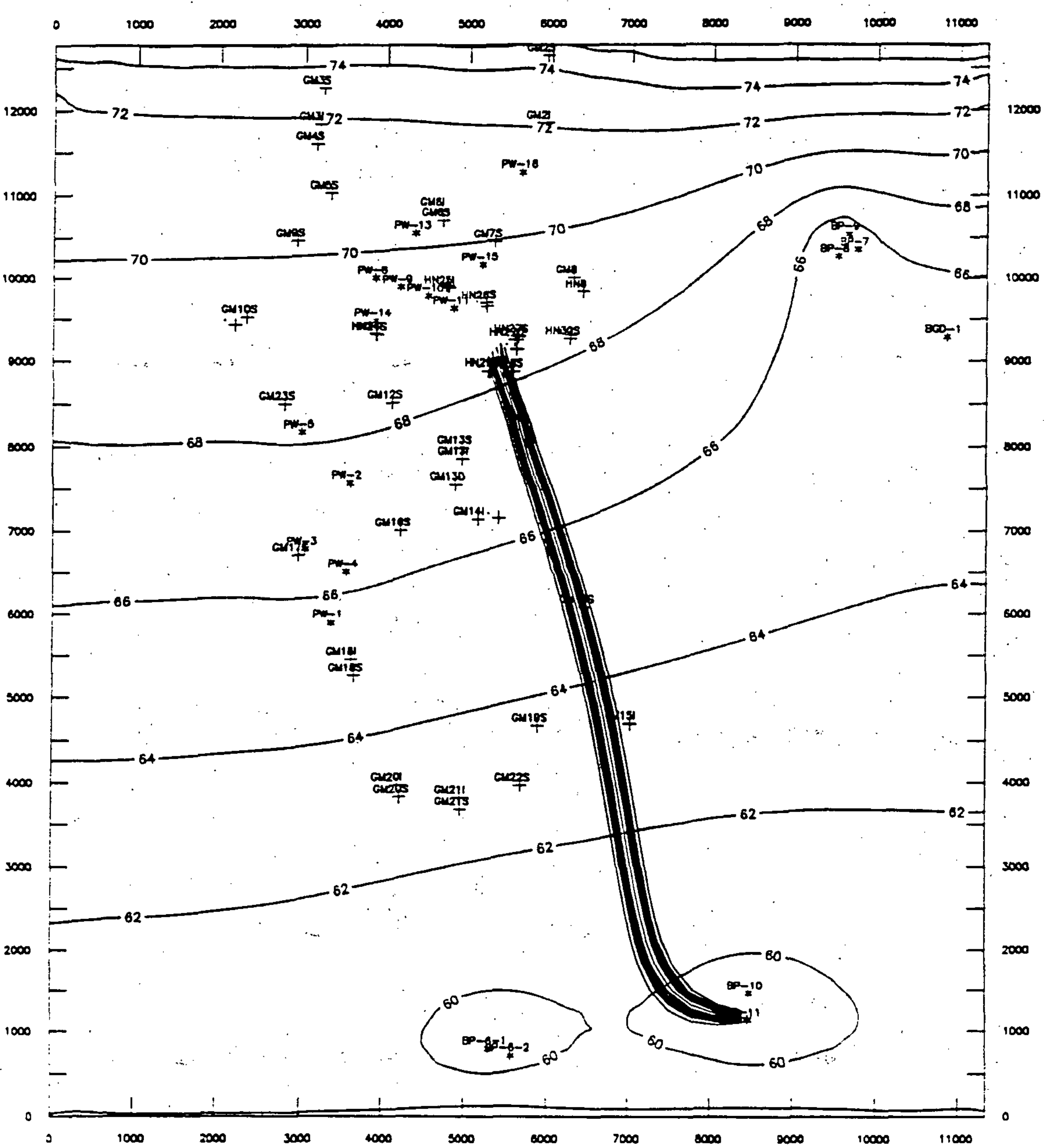
• = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 8-12
Particle Tracking Results - Capture Zones of BWD Wells - No Pumping at Grumman, BWD at Average Pumping Conditions.



* = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

Figure 8-13
Particle Tracking Results - Site 1 Release - No Pumping at Grumman, BWD at High Pumping Conditions.



* = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

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Figure 8-14
Particle Tracking Results - Capture Zones of BWD Wells - No Pumping at Grumman, BWD at High Pumping Conditions.

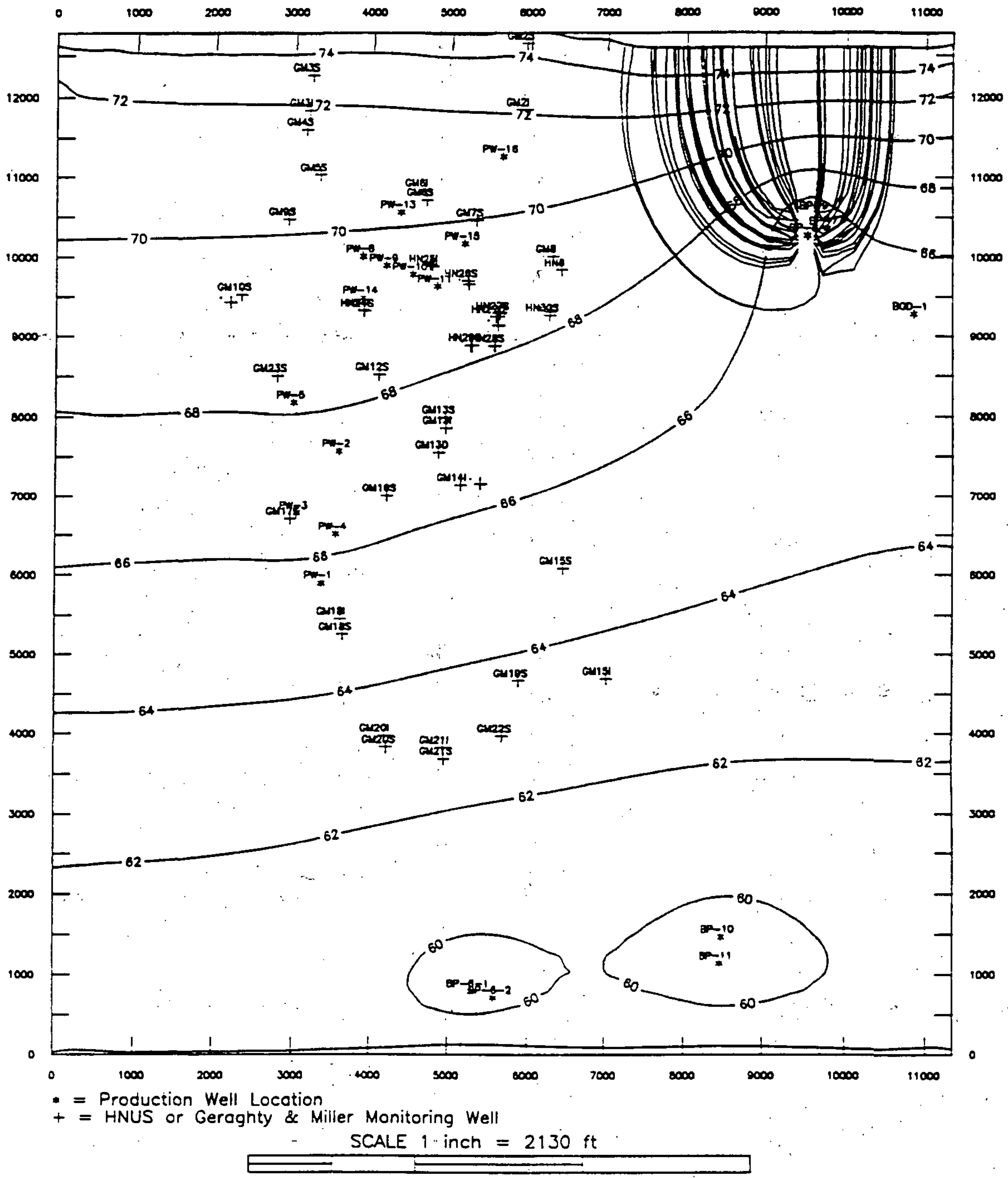
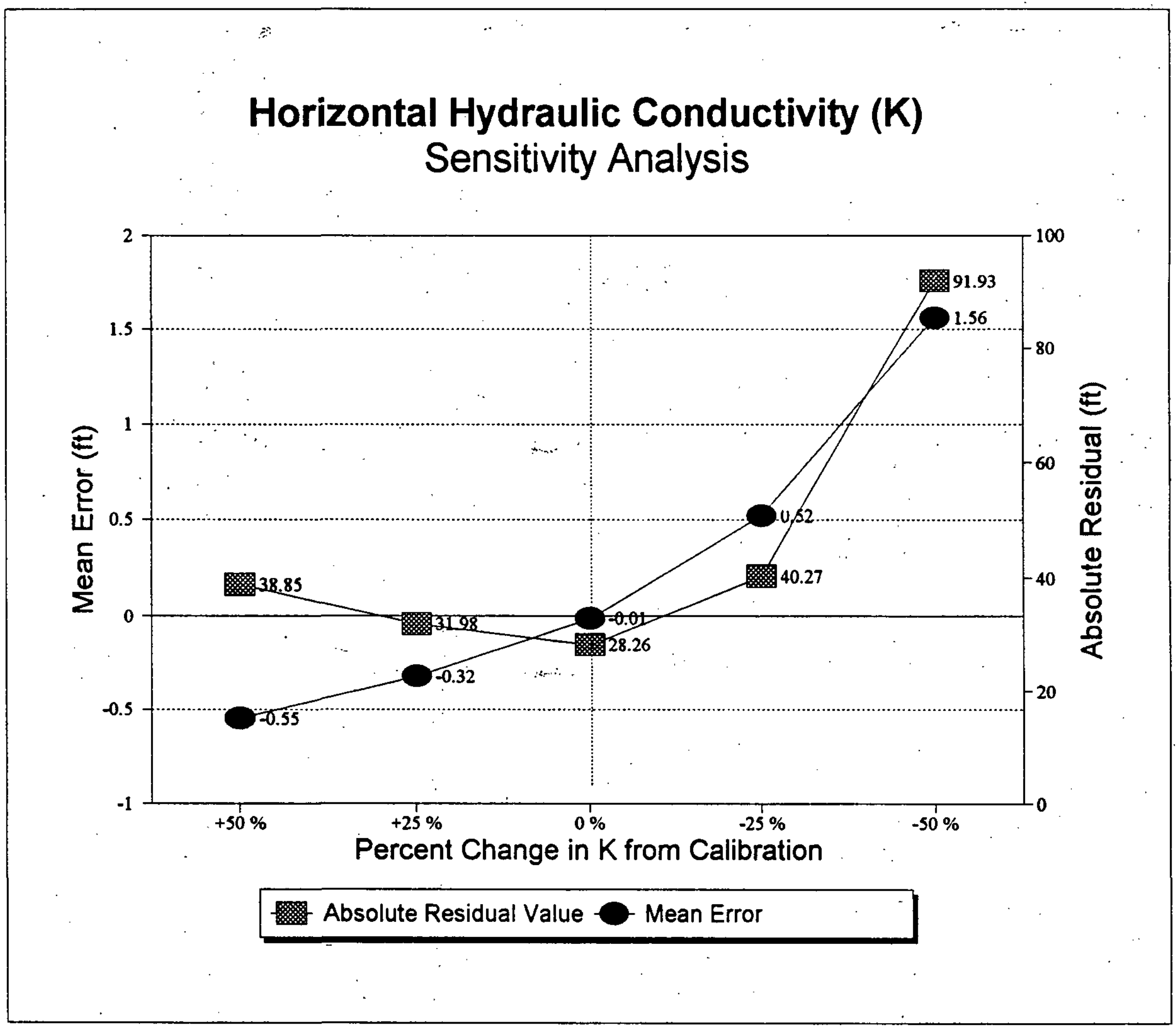


FIGURE 9-1
SENSITIVITY ANALYSIS RESULTS FOR HORIZONTAL HYDRAULIC CONDUCTIVITY (K)

Parameter	Percent Change in Parameter	Mean Error	Absolute Residual
K increased	+50 %	-0.55	38.85
K increased	+25 %	-0.32	31.98
Calibration Value	0 %	-0.01	28.26
K decreased	-25 %	0.52	40.27
K decreased	-50 %	1.56	91.93



results in a higher absolute residual value. Conversely, a decrease of 25% or 50% results in a higher mean error (i.e., modeled values are too high as the flow through the aquifer is reduced) and a higher absolute residual value. An decrease of 50% results in a significant increase in both mean error and absolute residual values, indicating the model results are sensitive to a decrease of greater than 25% of horizontal hydraulic conductivity in comparison to calibrated values. The model results are not highly sensitive to an increase of up to 50% and an decrease of up to 25% of horizontal hydraulic conductivity. However, while the model results may not be highly sensitive to changes in horizontal conductivity of this magnitude, these changes do produce less favorable solutions than the calibrated model.

9.2 VERTICAL HYDRAULIC CONDUCTIVITY

Vertical conductivity values were increased and decreased by 25% and 50% for the sensitivity analysis. For each parameter change, the model was run to a steady-state, and the mean error and absolute residual values were calculated and compared to the values for the calibrated values of parameters. The results of the sensitivity analysis are illustrated on Figure 9-2.

The results of the sensitivity analysis indicate that an increase in vertical hydraulic conductivity of 25% or 50% results in lower mean error values (i.e., the modeled values are too low) and results in a higher absolute residual value. Conversely, a decrease of 25% or 50% results in higher mean error (i.e., modeled values are too high) and a higher absolute residual value. A decrease of 25% results in minimal change in the model output, while an decrease of 50% results in a significant increase in both mean error and absolute residual values in comparison to calibrated values. This indicates the model results are sensitive to a decrease of greater than 25% of vertical hydraulic conductivity. The model results are not highly sensitive to an increase of up to 50% and a decrease of up to 25% for vertical hydraulic conductivity. However, while the model results may not be highly sensitive to changes in vertical conductivity of this magnitude, these changes do produce less favorable solutions than the calibrated model.

Fig.9-3 Sensitivity Analysis
HN-27S2 Drawdown for Pump Test #1

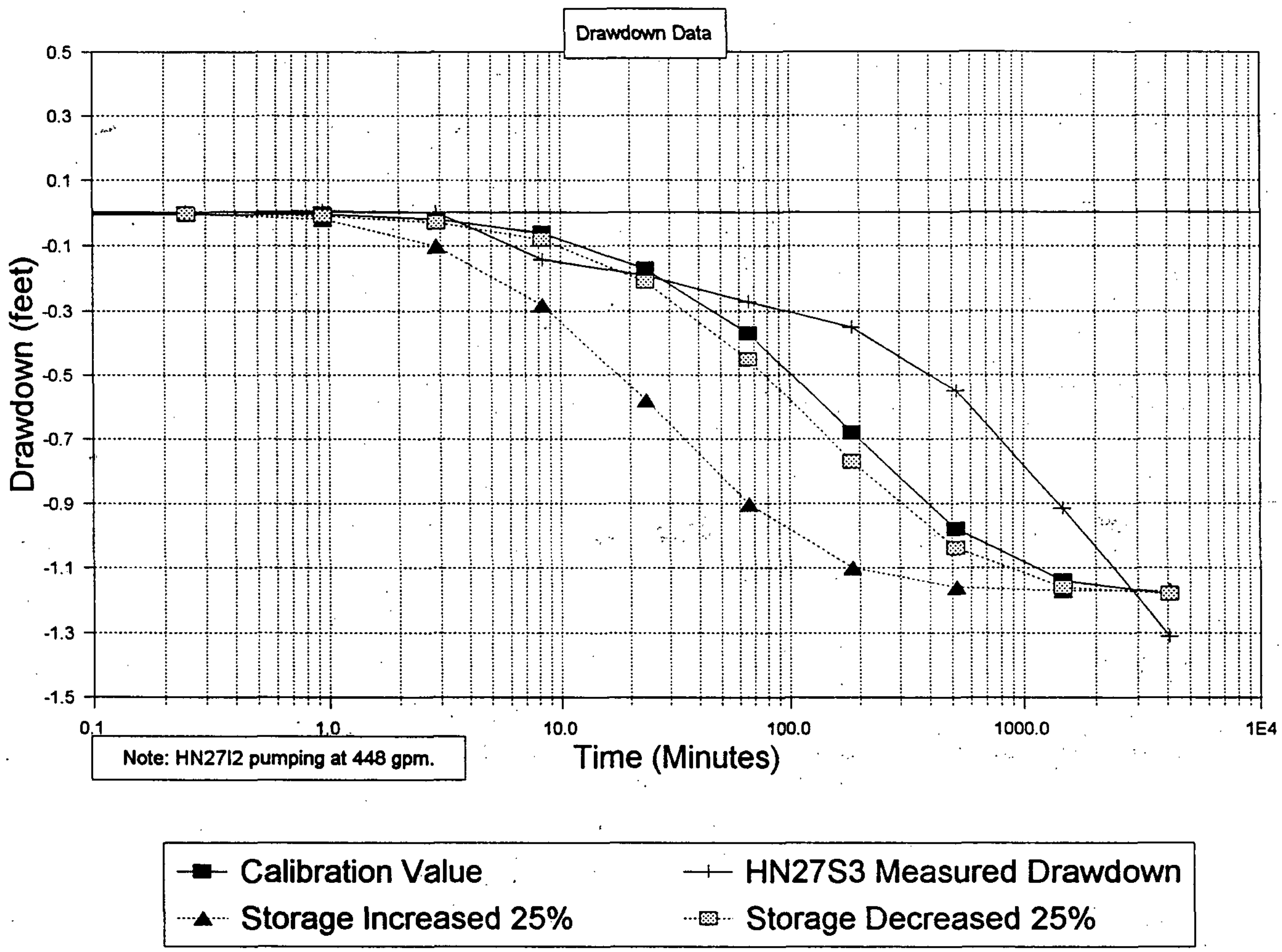


Fig.9-4 Sensitivity Analysis
HN-27S3 Drawdown for Pump Test #1

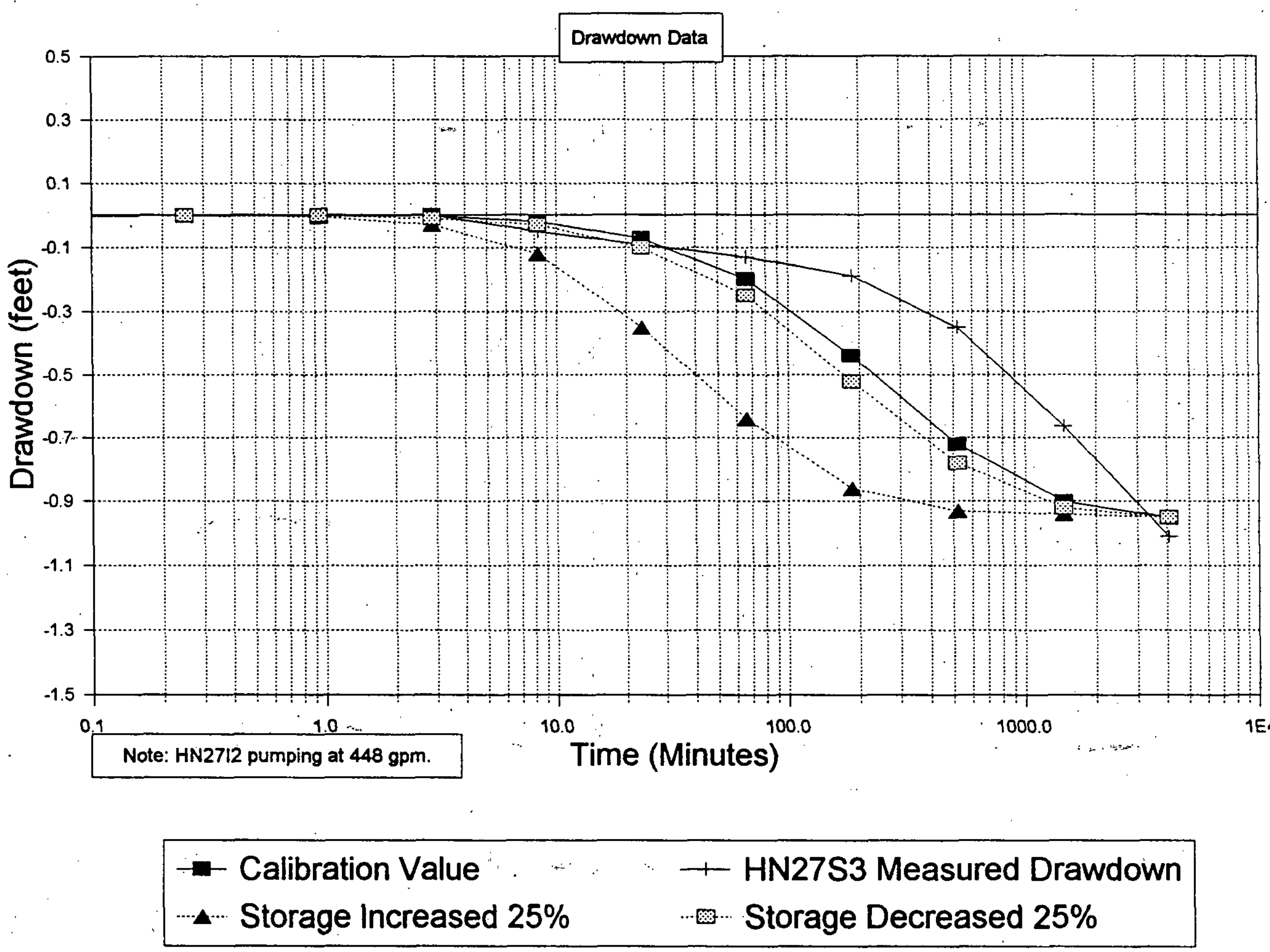


Figure 9-5 Sensitivity Analysis

HN-26I Drawdown for Pump Test #1

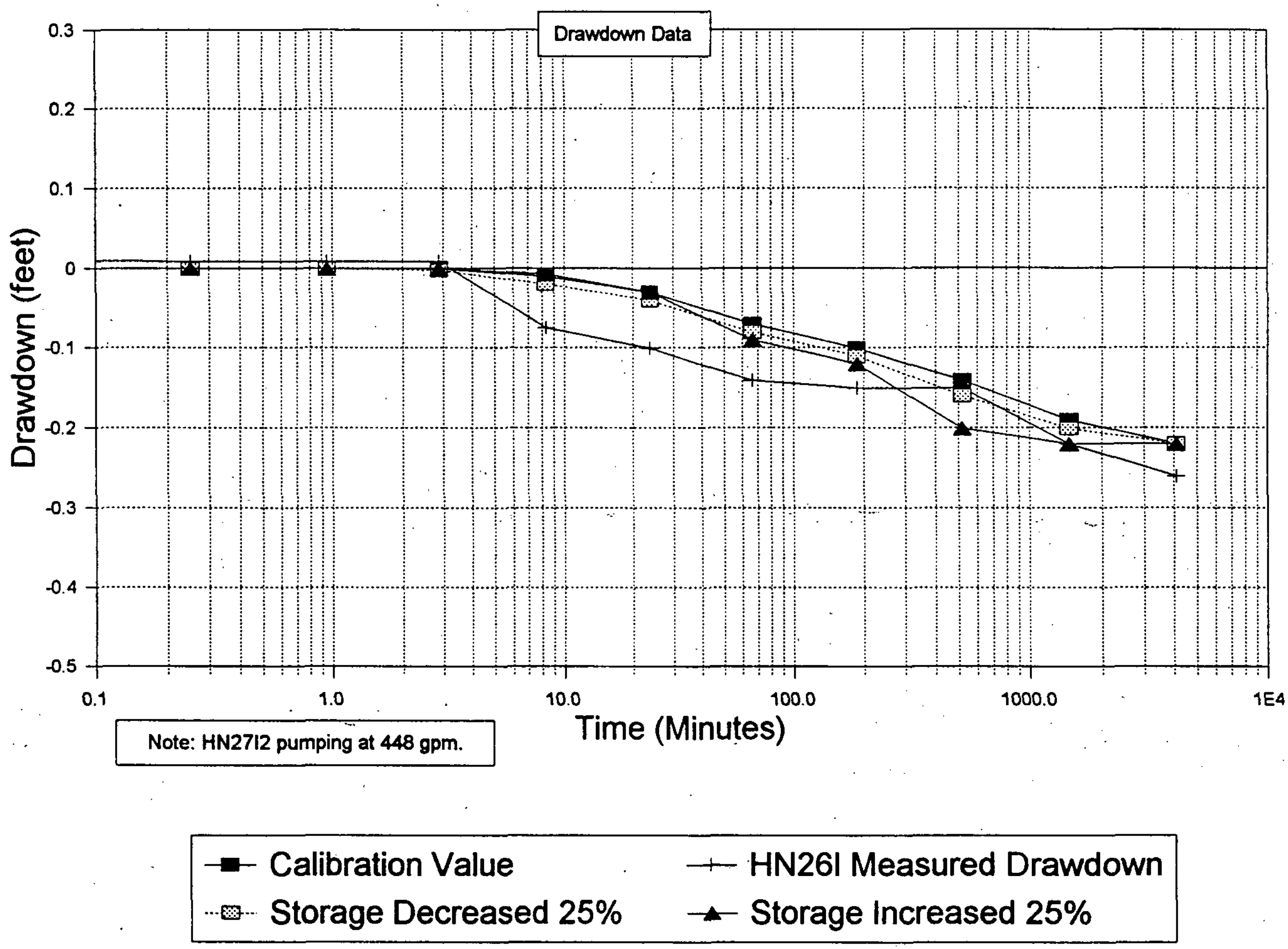


Figure 9-6 Sensitivity Analysis
HN-27I1 Drawdown for Pump Test #1

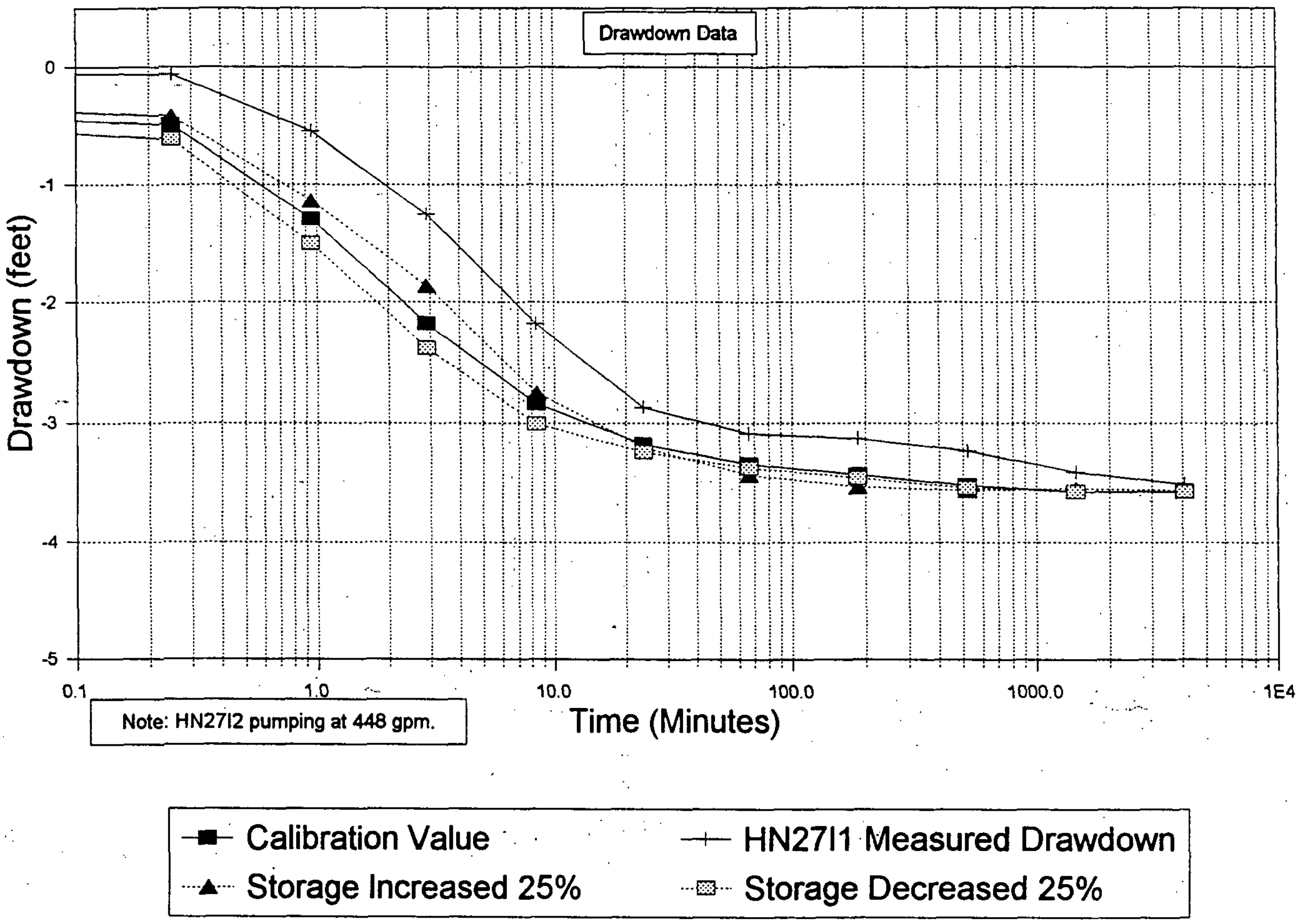


FIGURE 9-9
SENSITIVITY ANALYSIS RESULTS FOR POROSITY

PARTICLE	POROSITY DECREASED 25%		CALIBRATION VALUE	POROSITY INCREASED 25%	
NUMBER	TRAVEL TIME (DAYS)	% CHANGE	TRAVEL TIME (DAYS)	TRAVEL TIME (DAYS)	% CHANGE
1	10710	24.95	14270	17840	25.02
2	10580	25.02	14110	17640	25.02
3	13050	25.04	17410	21760	24.99
4	1105	25.03	1474	1842	24.97

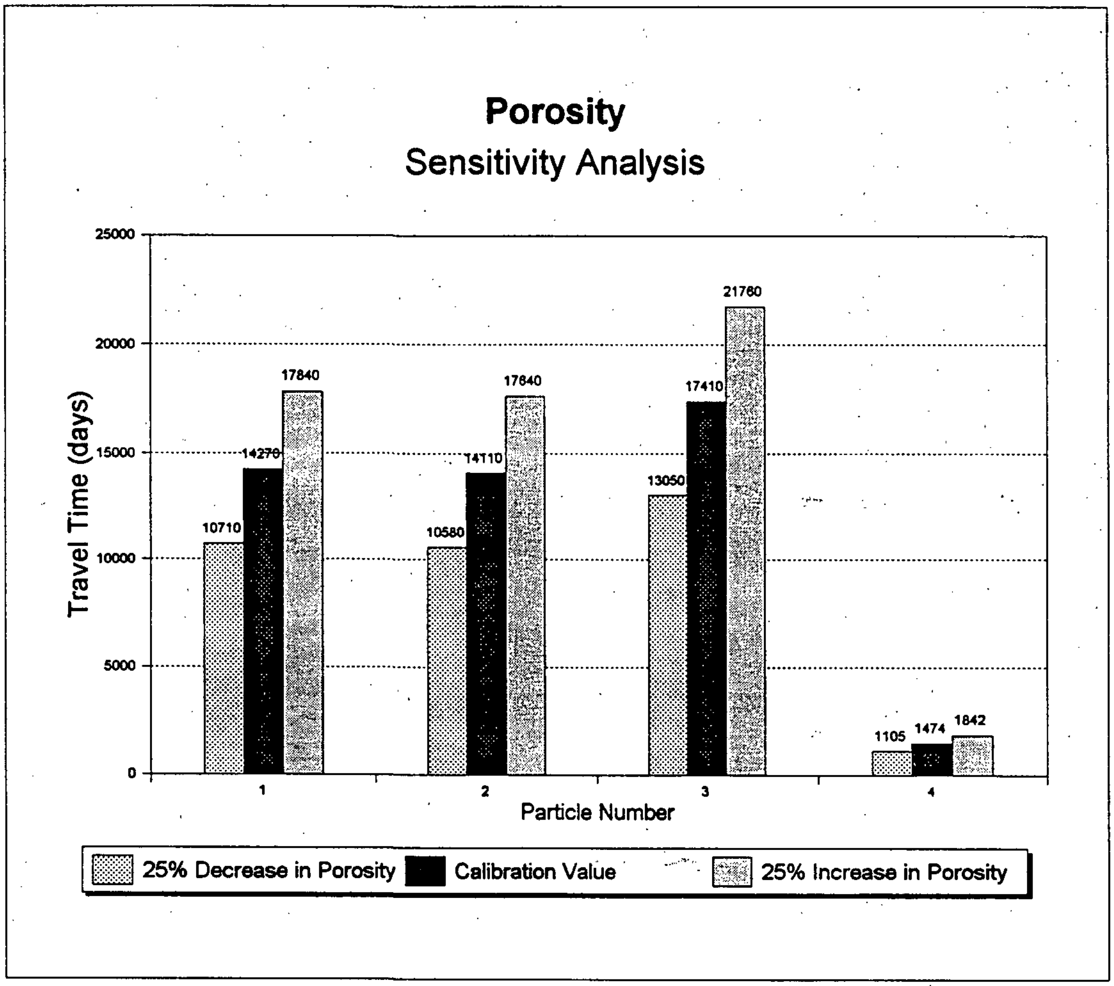
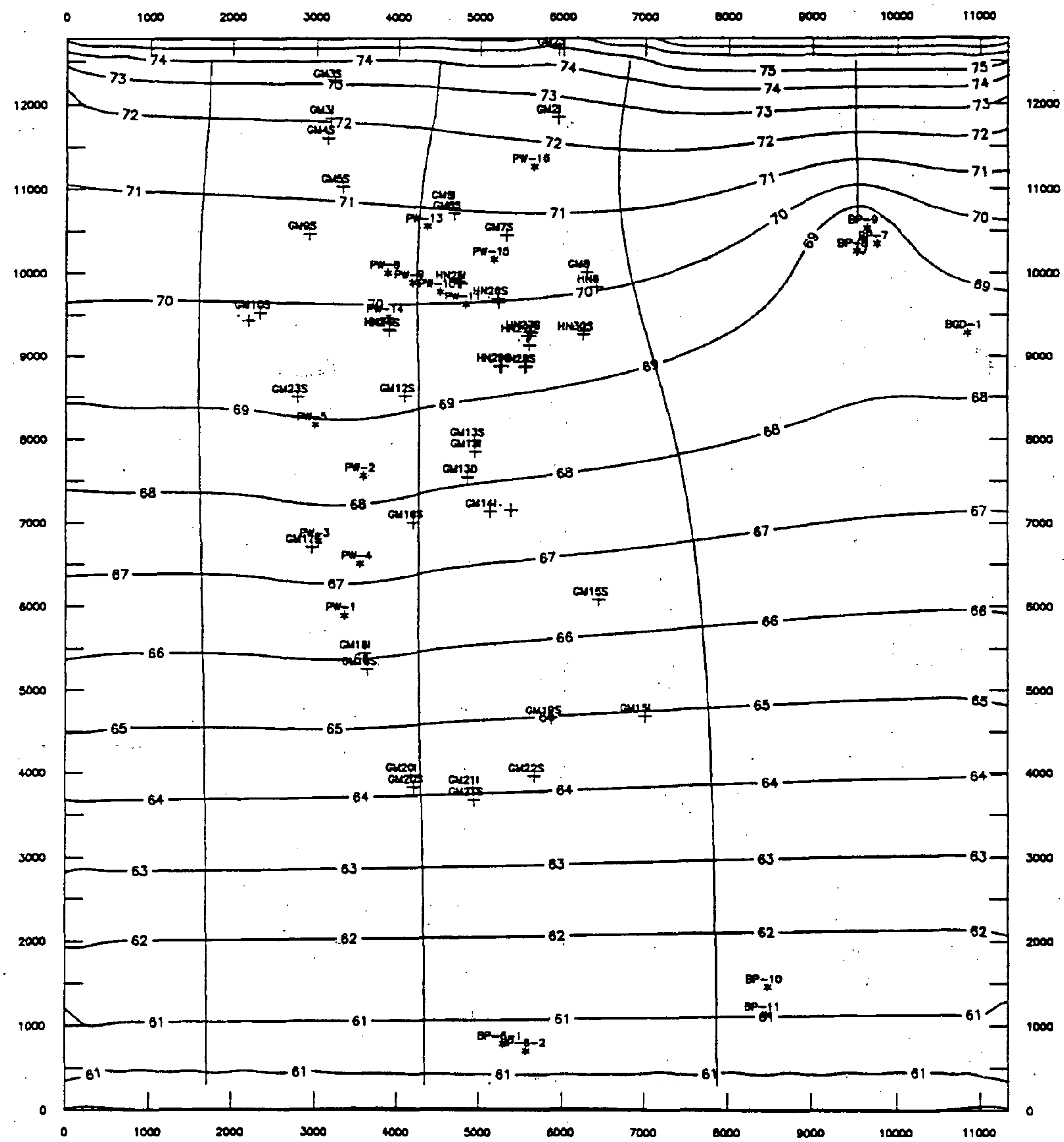


Figure 9-10
Particle Release Locations Used in Porosity Sensitivity Analysis.



* = Production Well Location
\+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

9.5 RECHARGE

Recharge values were increased and decreased by 25% and 50% for the sensitivity analysis. For each parameter change, the model was run to a steady-state, and the mean error and absolute residual values were calculated and compared to the values generated with the calibrated values. The results of the sensitivity analysis are illustrated on Figure 9-11.

The results of the sensitivity analysis indicate that a decrease in recharge of 25% or 50% results in lower mean error values (i.e., the modeled values are too low due to the decreased water flux into the system) and results in a higher absolute residual value. Conversely, an increase of 25% or 50% results in higher mean error (i.e., modeled values are too high due to more water entering the system) and results in a higher absolute residual value. Changes in the recharge to the system exhibit a linear (predictable) relationship to the mean error and absolute residual values, with an equal amounts of mean error increase and absolute residual error increase being incurred regardless of whether recharge is increased or decreased.

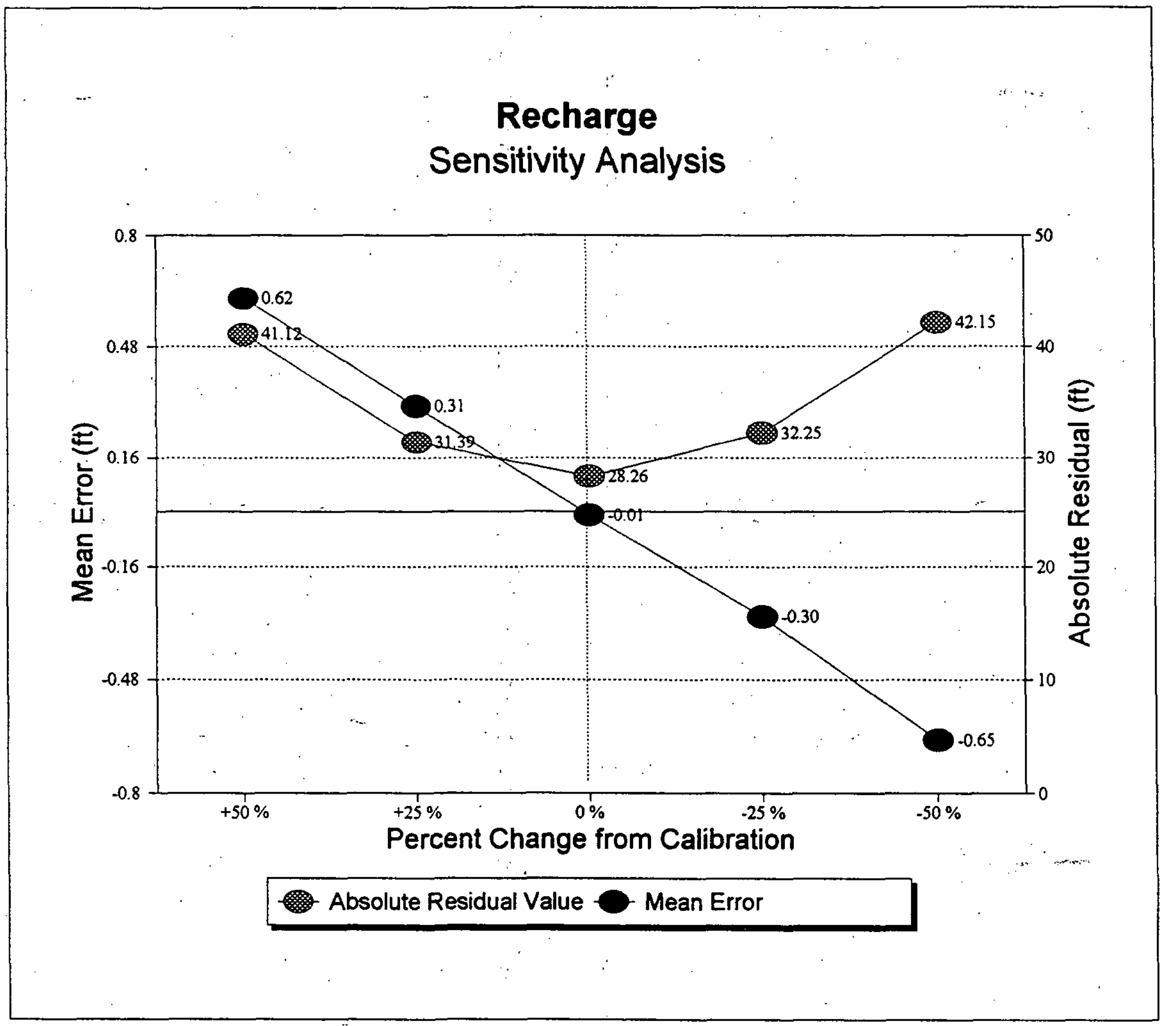
9.6 BOUNDARY CONDITIONS

To determine the effect of more distant boundaries on the capture zone of the eastern BWD wells (BP-07, BP-08, BP-09), the northern constant head boundary conditions in the MODFLOW model were moved 1400 ft to the north. This resulted in a 40% increase in the distance between the BWD wells to the northern constant head boundary. A sensitivity analysis was performed to determine whether a more distant constant head boundary would increase the size of the capture zone of the BWD wells and if additional particle movement could be expected from the NWIRP recharge basins to the BWD wells.

Two pumping scenarios were considered for the sensitivity analysis; an average pumping condition and a high pumping condition. In the average pumping condition Grumman wells were pumping at 1991/1992 average rates, and BWD wells were running at 120% of the 1991/1992 average rates. High pumping conditions had Grumman wells running at 75% of maximum capacity and BWD wells running at their actual (highest) capacity.

FIGURE 9-11
SENSITIVITY ANALYSIS RESULTS FOR RECHARGE

Parameter	Percent Change in Parameter	Mean Error	Absolute Residual
Recharge increased	+50 %	0.62	41.12
Recharge increased	+25 %	0.31	31.39
Calibration Value	0 %	-0.01	28.26
Recharge decreased	-25 %	-0.30	32.25
Recharge decreased	-50 %	-0.65	42.15



Results of each pumping condition are illustrated as the capture zone of the BWD wells under each pumping condition and constant head boundary location. Figures 9-12 and 9-13 show the capture zone of these wells under average and high pumping conditions with the northern constant head boundary in the location used during calibration. The results of the sensitivity analysis with a more distant constant head boundary are illustrated on Figures 9-14 and 9-15.

A comparison of the capture zones for the BWD wells under calibrated conditions (Figure 9-13) and the sensitivity analysis conditions for average pumping at the wells (Figure 9-14) show that these two conditions have capture zones of similar shapes. The capture zone of the BWD wells does not significantly increase if the north constant head boundary is moved 1400 ft north. Similar results are seen when comparing the capture zone of these wells under calibration conditions (Figure 9-13) with the sensitivity analysis conditions for high pumping at the wells (Figure 9-14). Under calibration conditions, 6 of 72 particles released from the BWD wells originate in the vicinity of the NWIRP recharge basins, while 8 of 72 particles released originate in the vicinity of the recharge basins. These sensitivity analyses indicate moving the north constant head boundary does not produce a significant change in the capture zones of the BWD wells.

Figure 9-12
Capture zones of BWD Wells - Calibration Location of North Constant Head Boundary - BWD at Average Pumping Rate.

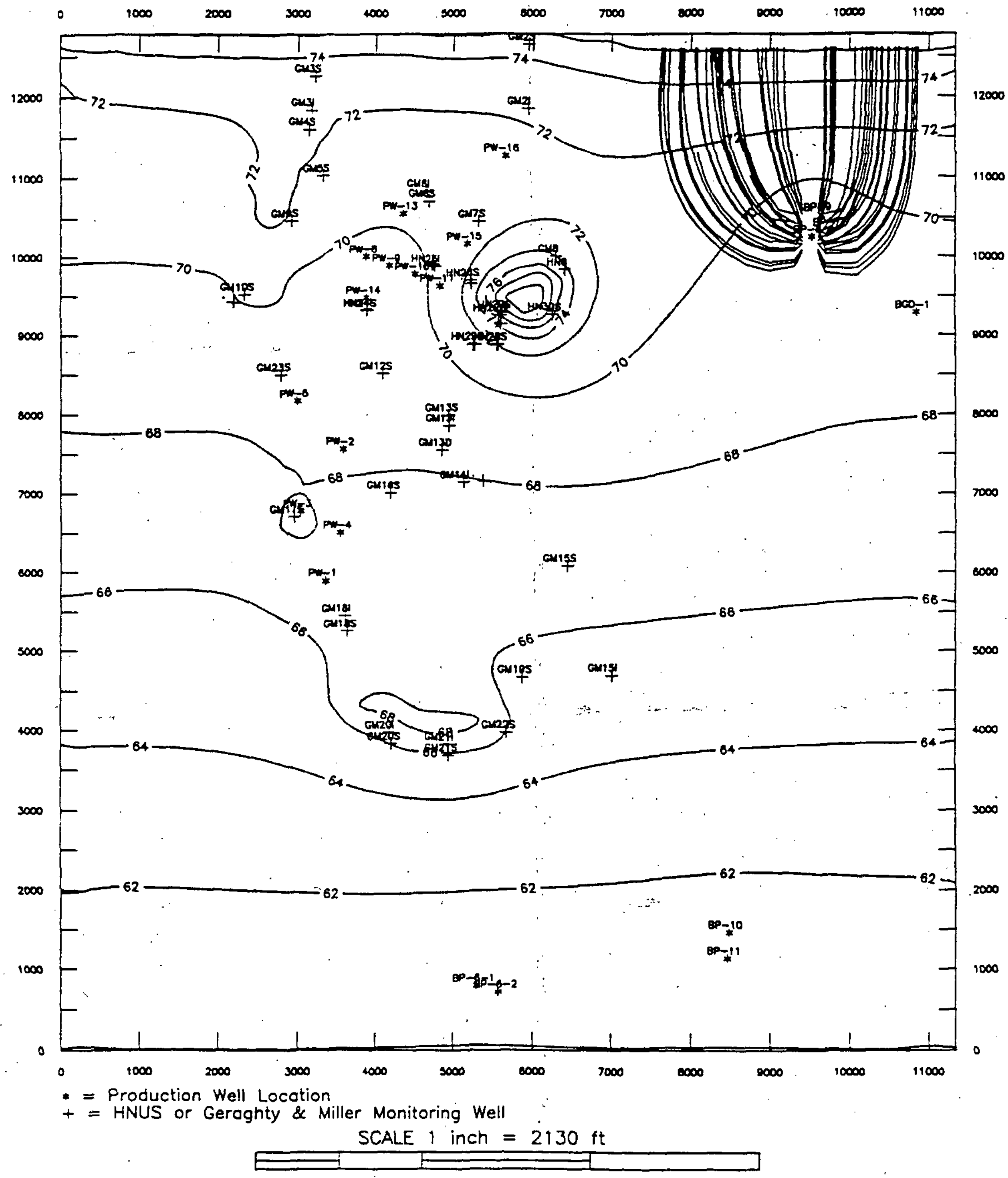
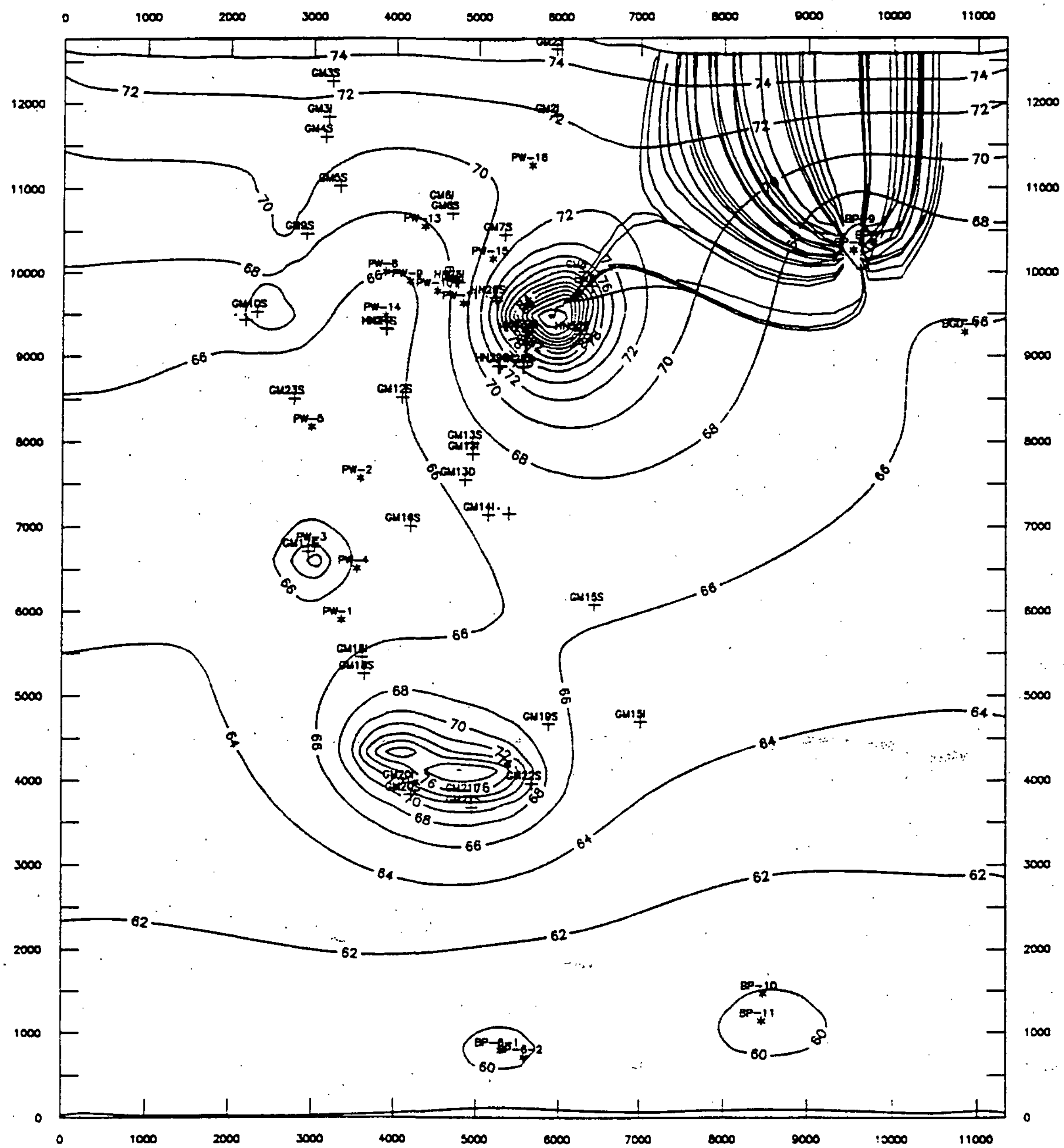
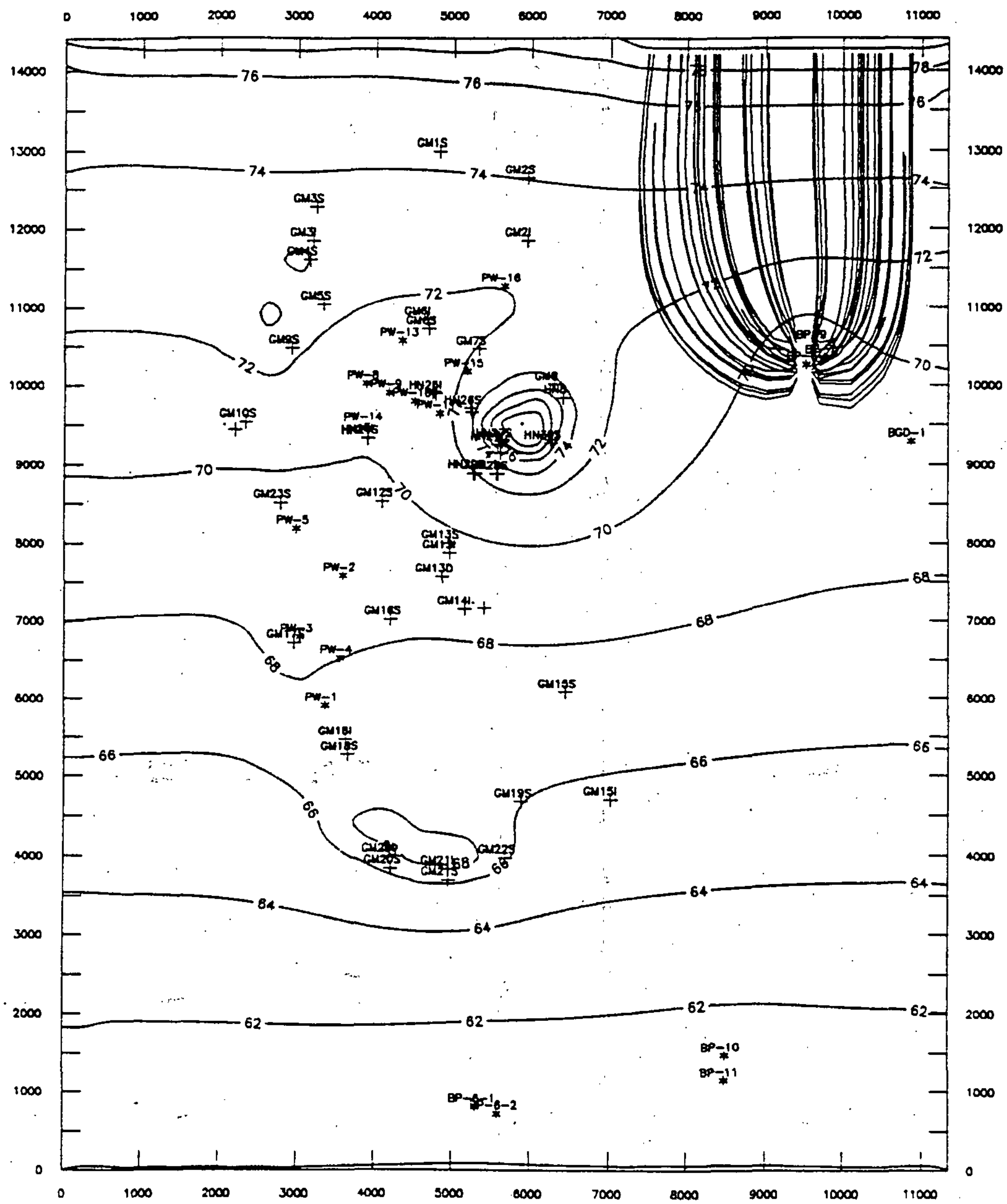


Figure 9-13
Capture zones of BWD Wells - Calibration Location of North Constant Head Boundary - BWD at High Pumping Rate.



* = Production Well Location
\+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2130 ft

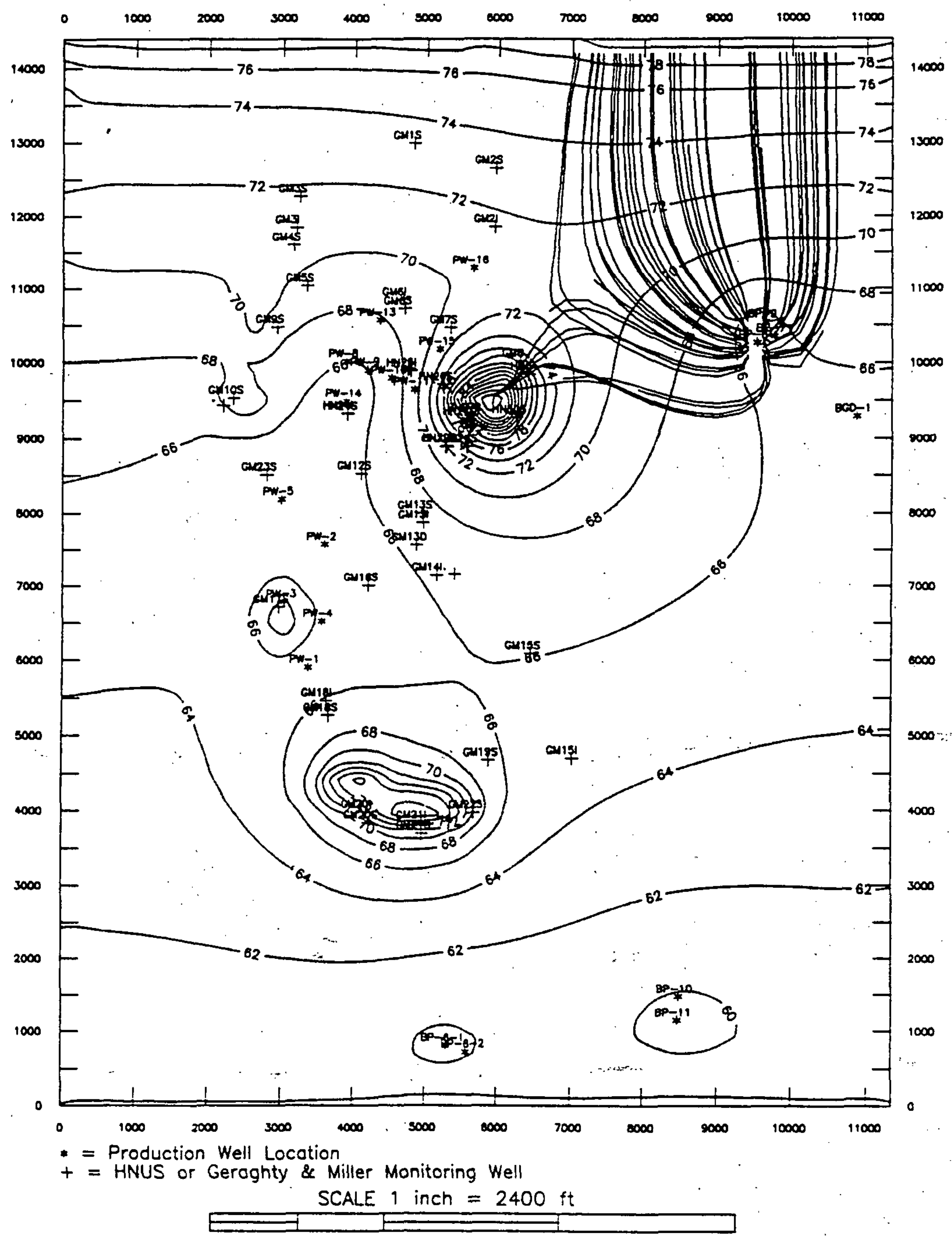
Figure 9-14
Capture zones of BWD Wells - Sensitivity Analysis Location of North Constant Head Boundary- BWD at Average Pumping Rate.



∗ = Production Well Location
+ = HNUS or Geraghty & Miller Monitoring Well
SCALE 1 inch = 2400 ft

Figure 9-15

Capture zones of BWD Wells - Sensitivity Analysis Location of North Constant Head Boundary- BWD at High Pumping Rate.



* = Production Well Location

\+ = HNUS or Geraghty & Miller Monitoring Well

SCALE 1 inch = 2400 ft

10.0 CONTAMINANT FATE AND TRANSPORT

10.1 GROUNDWATER: SUMMARY OF COMPUTER MODELING STUDY AND RESULTS

The following section summarizes the procedures and results of the computer modeling performed as part of the RI report for the Bethpage NWIRP.

10.1.1 Computer Modeling Objectives

The general objectives of the RI computer modeling were to provide data on the overall groundwater flow in the area of the NWIRP and to determine the potential flow directions of contaminants which may originate on the site. The specific objectives of the computer modeling at Bethpage NWIRP are listed below:

- Provide a general characterization of the subsurface conditions underlying Bethpage NWIRP.

- Develop a flow model which accurately represents groundwater flow in the area around the Grumman site, with an emphasis on the groundwater flow in and around the NWIRP.

- Model the flow directions of simulated contaminant releases under a variety of production well and NWIRP recharge basin pumping conditions.

10.1.2 Summary of Modeling Approach

The flow model was developed in several related steps, which are as follows; (1) Collect existing data and construct the conceptual model, (2) select the appropriate numerical groundwater model,

(3) input initial parameters into model, (4) perform calibration on two months of steady-state data, and two sets of transient pump test data (5) perform validation on two months of steady-state data, (6) perform particle tracking simulations, (7) conduct sensitivity analysis for flow model parameters.

10.1.3 Conceptual Model

To accurately simulate the behavior of groundwater and particle movement, it is first necessary to obtain a detailed understanding of the geologic and hydrogeologic factors which control groundwater flow at a site. The conceptual model of the groundwater system was developed from information gathered on site conditions during a literature review conducted prior to construction of the model. Initial values of geologic and hydrogeologic parameters were obtained from a variety of literature sources and from two pumping test performed at the NWIRP.

Key features of the conceptual model are:

- The water table is present within the upper portion of the Magothy aquifer across most of the modeled area. The Magothy aquifer is considered to be the most significant water-bearing unit in the vicinity of the NWIRP site.

- The upper glacial and Magothy units are considered to function as a single aquifer, as no barrier exists between these units to prevent the exchange of water.

- All Grumman production wells, recharge basins and BWD wells are located in the upper glacial aquifer, or within the Magothy aquifer.

- The base of the flow system is the Raritan Clay unit, which is considered to be impermeable.

- The aquifer is considered to be unconfined.

- No natural surface water bodies are present within the modeled area which

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significantly effect groundwater flow in the model area.

Key features of the computer model grid are:

- The model grid covers the NWIRP, Grumman property, and BWD wells to the east and south.

- Model grid columns are oriented parallel to the normal (non-pumping) groundwater flow.
- Grid spacing is most dense in the area of the NWIRP, where the direction of groundwater flow is of primary interest. Grid spacing widens towards the edge of the grid.

- The model grid consists of five layers, which were determined based on the screened intervals of shallow intermediate and deep monitoring wells. Layer 1 contains shallow wells, layer 2 contains intermediate wells, layer 3 contains deep wells and one BWD well, layer 4 and 5 contain Grumman production wells and BWD wells.

- Constant head boundaries are present along the north and south grid boundaries, and no flow boundaries are present along the east and west grid boundaries.

10.1.4 Computer Code Selection

The modular three-dimensional finite-difference groundwater flow model (known as MODFLOW) was chosen to be used for this modeling project because it is capable of simulating the conceptual model developed for the NWIRP site. MODFLOW was developed by the U. S. Geological Survey to simulate groundwater flow in a variety of situations (Mc Donald and Harbaugh, 1988). This model can be used for two-dimensional or three-dimensional applications, and can simulate the effects of wells, recharge, drains, and rivers as well as a variety of boundary conditions. MODFLOW has been used extensively at hazardous waste sites for simulation of groundwater flow, evaluation of remedial alternatives, and can be used in conjunction with other programs for modeling of contaminant transport and particle tracking. MODFLOW uses a block-centered grid for solving the finite-difference groundwater flow equations.

MODPATH is a three-dimensional particle tracking code that was developed by the U. S. Geological Survey (Pollock, 1989). MODPATH operates separately from MODFLOW, and utilizes heads calculated in MODFLOW to determine the direction of particle movement with time. Particle flow directions can be traced forward in time to determine where particles released from a potential contaminant source may move, or particles can be tracked in reverse to determine well capture zones.

10.1.5 Model Calibration

Model calibration refers to a demonstration that the model is capable of producing water elevations which are comparable to water elevations measured on site. Calibration included performing steady-state simulations for two separate pumping conditions at the Grumman site; low pumping conditions for Grumman production wells during February 1992, and high pumping conditions for Grumman production wells during August 1992. Calibration also included conducting transient simulations for two pumping tests which were carried out at the NWIRP site.

Model calibration was conducted to generate a best fit for both steady-state and transient conditions. Calibration was performed interactively between transient and steady-state simulations. The final calibrated model minimized the model error for both the steady-state and transient simulations.

Steady-state calibration simulated two monthly pumping scenarios. Simulated water elevation data was compared to measured data at 61 monitoring wells across the modeled area. Steady-state simulations were run until there was less than .0001 ft of change in head during one iteration of the simulation. Both steady-state and transient model calibration was performed by adjusting initial values of aquifer parameters and boundary conditions until an acceptable match of the modeled data was achieved when compared to observed measurements. To more accurately represent natural conditions, recharge was added to 3 recharge basins on Hooker-

Ruco property, and to one recharge basin in the vicinity of well GM-15S during model calibration. These basins were activated to compensate for recharge which may have occurred at these basins during the months considered in the model calibration.

Transient (stressed) conditions were calibrated by simulating two pumping tests performed at the NWIRP site. These pumping tests produced drawdowns within a small portion of the model grid and transient calibration efforts were focused on this section of the model. Simulated drawdowns were compared to measured drawdowns for the transient calibration runs.

Calibration Criteria

The steady-state flow model was considered calibrated when the modeled steady-state simulations were within 2.0 ft of measured values at the monitoring wells. The calibration criteria was determined as one-half the natural water table fluctuation across the site. This calibration criteria of ± 2.0 ft was met for all of the 61 monitoring wells on site, with the exception of 8 monitoring wells. These wells which fall outside the calibration criteria are located in the immediate vicinity of active recharge basins or production wells, which may have effected the calibration results. A more rigorous calibration criteria of ± 1.0 ft was met for the modeled versus measured drawdowns for the two transient pumping test simulations. The ± 1.0 ft calibration criteria was used for the pumping test simulations because these pumping tests effected a small portion of the model grid where grid spacing is most dense, and flow in and around the NWIRP is of primary interest as potential sources of contaminants (Site 1) are known to exist in this area..

Calibration Results

For each steady-state calibration run, the difference in head between the measured and modeled heads was noted. The measured minus modeled value indicates if the measured water elevation at a well is within the calibration criteria. In addition to this value, two other quantitative calculations were preformed for the calibration runs to determine how closely the modeled data fit the measured data.

The sum of the differences of modeled data to measured data (referred to as the mean error) indicates the amount of positive or negative model error for the calibration run. A zero value of mean error indicates equal amounts of positive and negative model error, (i.e., the model predictions are not consistently high or low). Final calibration results for low pumping conditions have a mean error of -0.01 ft for low pumping conditions, and 0.02 ft for high pumping conditions. The mean error was minimized during model calibration. A small value of mean error alone does not indicate a good calibration, as both positive and negative mean errors are incorporated and may cancel out. For this reason, an additional measure of model accuracy (absolute residual value) was calculated.

The absolute residual value is the sum of the absolute values of the differences between measured and modeled data for each monitoring well. A low absolute residual value indicates a good match between measured and modeled data, with a zero value indicating an exact match between measured and modeled data. The absolute residual value for low pumping conditions was 28.26 ft, and for high pumping conditions the absolute residual value was 36.64 ft. The absolute residual value for low pumping and high pumping conditions was minimized during calibration, and these absolute residual values were considered to be acceptable for these simulations.

The outlier wells that fall outside the calibration criteria were not included in the calculation of mean error or absolute residual error because these wells were interpreted to be influenced by active recharge basins and production wells and, therefore do not accurately reflect the modeled conditions. Pumping rates used in the model were derived from monthly averages at each production well and do not reflect daily fluctuations in recharge basin water levels or production well pumping rates. The measured water elevations represent a 'snap-shot' of water conditions, while the modeled conditions reflect steady-state conditions. Therefore, water elevations taken at monitoring wells in the immediate vicinity of active recharge basins or production wells may be influenced by pumping or recharge activities. The majority of monitoring wells are distant enough from recharge basins or pumping wells so that they are not effected by short-term fluctuation caused by pumping or recharge. The average pumping rates used in the model can accurately simulate water levels, as indicated by the close fit of modeled to measured water elevations at most of the monitoring wells during calibration.

In addition to the statistical checks made on calibration solutions noted above, the water balance of each calibration run was checked. This water balance measurement is generated by the MODFLOW model, and is an independent check on the total amount of water entering and leaving the flow system. All calibration runs fell below the ± 0.50 % water balance error criteria.

Statistical analysis on the calibration results were performed to determine how well the model data matched the measured data, and to determine if any trends were present in the distribution of model error. Linear regression data for the calibrated steady-state model indicates that a nearly direct relationship exists between the modeled and measured data. Similarly, a linear regression for the modeled and measured drawdowns for pumping test #1 shows a nearly direct relationship between measured and modeled results. The simulation of pumping test #2 was more difficult to model due to the small amounts of drawdowns produced (< 1.0 ft) in the observation wells. The regression data for this data shows more scatter and a less direct fit of the modeled data. Residual contour plots, which show a contour plot the model error for the steady-state simulations, indicate no significant trends were present in the modeled data.

10.1.6 Model Validation

Model validation is a check on how well the model can predict a set of water elevations, utilizing the model parameters established during calibration. Model validation for the flow model consisted of entering the known pumping rates for production wells and recharge basins for two separate months, running the model to a steady-state, and comparing model output to measured data for those months. Two validation scenarios were simulated, January 1992 and July 1992.

These two data sets were not used during model calibration and represent independent data sets for model validation. The January and July data sets were chosen for validation because these months occur immediately before February and August 1992, which were used during calibration. The January and July data was considered to represent the most similar boundary conditions to those used for calibration as they occur in the same seasons as the calibration runs. Precipitation data indicates that January and July 1992 are more similar to February and August 1992 (rather than March and September, the other months considered for validation). Using months in similar seasons, with similar amounts of precipitation for calibration and validation is important because the total precipitation will effect the water elevations at the north and south constant head boundaries, which effect water elevations across the modeled area.

The January 1992 validation results show that the difference of modeled to measured water elevation falls within the ±2.0 ft criteria for 56 of 58 monitoring wells. Two wells which fall outside the ±2.0 ft criteria are monitoring wells GM-6I and GM-17S. These two wells are in the immediate vicinity of a production well and recharge basin, and are considered outlier wells and may be biased by the nearby pumping and recharge activity.

Results of the July 1992 validation show that the difference of modeled to measured water elevation falls within the ±2.0 ft criteria for the majority of the monitoring wells. A total of eight wells fall outside the calibration criteria. Five of these wells, GM-6I, GM-17S, HN-8D, HN-29D and HN-30I, are in the immediate vicinity of a production well or recharge basins, which are considered outlier wells and were not included in calculation of mean error because they may be effected by pumping or recharge activities. Three monitoring wells, GM-7D, GM-8S and HN-28I showed a modeled to measured difference of greater than ±2.0 ft. The remaining 51 of 59 monitoring wells fall within the ±2.0 ft criteria.

10.1.7 Particle Tracking

MODPATH, a module of MODFLOW, was used to track the locations of particles after a simulated release of contaminants from suspected source areas. Particle tracking was performed to determine the possible directions and rates that contaminants will move after a release. Several particle tracking scenarios were performed, each under a different pumping condition of Grumman production wells and recharge basins, and with different BWD well pumping rates. The particle tracking program MODPATH utilizes the groundwater flow data generated by MODFLOW and simulates advective transport of particles. Other contaminant transport parameters such as diffusion, dispersion, contaminant half-life are not considered in the MODPATH simulations. All MODPATH simulations were performed using the aquifer parameters determined during model calibration, for pumping scenarios run to a steady-state.

Particle tracking analysis is used to trace out flow paths, expressed as lines, by tracking the movement of infinitely small imaginary particles placed in the flow field. This process may also be used to determine the capture zone of a well by releasing particles in a grid block, generally a well, and tracking the particles in reverse along pathlines to determine their source.

Particle Release Locations

Particle tracking analysis was performed for three separate release locations, listed below:

- Particles were released from possible contaminant sources at Site 1.
- Particles were released from possible contaminant sources at the NWIRP recharge basins.
- Particles were also released at the eastern BWD wells (BP-07, BP-08 and BP-09)

Particle tracks from the two potential source areas (Site 1 and the NWIRP recharge basins) were tracked in the forward direction to determine where particles will move after a simulated release. Particles were released from each of the three BWD wells to the east of the NWIRP. These particles were backwards tracked to determine where they originated from and to define the capture zone of each well.

Pumping Scenarios

Three pumping conditions were considered for particle tracking simulations. These pumping conditions were determined based on past, current and potential future pumping configurations at the Grumman production wells, recharge basins, and BWD wells. The emphasis of these simulations was to determine where particles will move after a release from potential contaminant sources and what effect, if any, these potential contaminant sources will have on BWD wells. The pumping scenarios are summarized below in Table 10-1:

TABLE 10-1

SUMMARY OF PUMPING CONDITIONS USED IN PARTICLE TRACKING SIMULATIONS
NWIRP BETHPAGE, NEW YORK

Pumping Scenario	Grumman Production Well / Recharge Basin Pumping Rate	BWD Wells Pumping Rate	Reason Considered
Current Conditions	1991, 1992 average pumping rate/recharge rate	1991, 1992 average pumping rate	Current average conditions.
High Pumping at Grumman, Scenario 1	All wells at 75% of maximum pumping rate/recharge rate	1991, 1992 average pumping rate	Likely historic conditions.
Scenario 2	All well at 75% of maximum pumping rate/recharge rate	Maximum pumping rate	Potential worst case historic conditions.
No Pumping at Grumman, Scenario 1	No pumping or recharge	1991, 1992 average pumping rate	Potential future scenario.
Scenario 2	No pumping or recharge	Maximum pumping rate	Potential future scenario.

Current conditions

Current conditions were simulated in order to determine where contaminants may be moving under the pumping conditions that exist currently. Production well pumping rates for current conditions at the Grumman site were determined from 1991 and 1992 average pumping rate data. BWD wells production rate data was determined from 1991 and 1992 average pumping rate data. The BWD wells were considered to be pumping at 120% of 1991 and 1992 rates, and well BP-09 was considered to be active although it was taken off-line in 1991. These assumptions represent conservative estimates of the current conditions at the BWD wells. Three recharge basins were considered to be active on Hooker-Ruco property, recharging the aquifer at a rate of 202 gpm per basin (the rate determined during model calibration).

Figures which illustrate the particle tracking pathlines for the current pumping situation are provided in Section 8.0 of this Appendix.

Particle Tracking Results and Conclusions - Current Conditions:

- All particles released from Site 1 under current pumping conditions are captured by Grumman PW-01.
- Particles released from the NWIRP recharge basins show that 30% of particles released are captured by Grumman production wells PW-01, PW-09, PW-10, PW-1, PW-15 and PW-16. The remaining 70% of the particles flow to the south constant head boundary. No particles from the NWIRP recharge basins are captured by BWD wells BP-10 or BP-11.
- The capture zone for BWD wells BP-07, BP-08 and BP-09 extends into the north constant head boundary.

High Pumping Conditions

The high pumping conditions were simulated to determine where particles may have moved from contaminant sources during past pumping conditions. Before 1985 higher rates of pumping/recharge at the Grumman production wells and recharge basins may have occurred due to the increased manufacturing activity at the facility. High pumping conditions at Grumman were simulated by pumping all 14 production wells at 75% of maximum capacity. Three recharge basins were considered to be active on Hooker-Ruco property, recharging the aquifer at the rate of 202 gpm per basin (the rate determined during model calibration).

Average and high pumping scenarios at the BWD wells were considered for high pumping conditions at Grumman production wells (as shown in Table 10-1). Average BWD well pumping conditions were simulated by pumping at the rate determined from 1991 and 1992 average pumping rate data. The BWD wells were considered to be pumping at 120% of 1991 and 1992 rates, and well BP-09 was considered to be active although it was taken off-line in 1991. These assumptions represent conservative estimates of the current conditions at the BWD wells. High pumping conditions at the BWD wells were also simulated. In this scenario all BWD wells were pumping at their actual (highest) capacity.

Particle Tracking Results and Conclusions - Grumman High Pumping Conditions, BWD Wells at Average Pumping Conditions

- All particles released from Site 1 are captured by PW-14 and PW-05.

- 73% of particles released from the NWIRP recharge basins are captured by the Grumman production wells, 24% reach the south constant head boundary, while 3% of particles reach BP-08 from the NWIRP recharge basins.

- The capture zones for BWD wells BP-07, BP-08 and BP-09 extend primarily into the north constant head boundary. Some particles originate in the vicinity of the NWIRP recharge basins. Three particles (4% of total) move from the north recharge basins to BP-08, while two particles (3% of total) move from northwest of the NWIRP recharge basins to BP-09.

TABLE 10-2
SUMMARY OF PARTICLE TRACKING RESULTS
NWIRP BETHPAGE, NEW YORK

Grumman Pumping Conditions	BWD Pumping Conditions	Particle Release Location	Number of Particles Released	Percentage of Particles Reaching Each Location					
				Grumman PW/Basin	Min./Max. Travel Time	Constant Head	Min./Max. Travel Time	BWD Wells	Min./Max. Travel Time (yrs.)
Current Conditions	Current Conditions	Site 1	48	100 %	14.8 / 53.5	0%	0	0%	0
		Recharge Basins	96	30%	2.4 / 13.8	70%	20.4 / 55.5	0%	0
		BWD Wells (1)	72	0%	--	100%	1.7 / 21.6	--	--
High	Average	Site 1	48	100%	3.8 / 11.8	0%	--	0%	0
		Recharge Basins	96	73%	0.8 / 40.4	24%	20.7 / 58.2	3%	10.4 / 24.1
		BWD Wells (1)	72	7%	7.4 / 18.6	93%	1.6 / 34.9	--	--
High	High	Site 1	48	100%	4.0 / 11.6	0%	0	0%	0
		Recharge Basins	96	65%	0.8 / 30.3	2%	30.9 / 69.9	33%	7.4 / 49.5
		BWD Wells (1)	72	8%	7.11 / 15.4	92%	1.2 / 26.6	--	--
No Pumping	Average	Site 1	48	0%	0	100%	49.7 / 58.5	0%	0
		Recharge Basins (2)	0	--	--	--	--	--	--
		BWD Wells (1)	72	0%	0	100%	2.8 / 18.8	--	--
No Pumping	High	Site 1	48	0%	0	0%	0	100%	48.8 / 58.0
		Recharge Basins (2)	0	--	--	--	--	--	--
		BWD Wells (1)	72	0%	0	100%	1.7 / 30.9	--	--

(1) Capture zone analysis performed for BWD wells.
(2) Recharge basins inactive during No Pumping conditions.

Particle Tracking Results and Conclusions - Grumman High Pumping Conditions, BWD Wells at High Pumping Conditions

- All particle released from Site 1 are captured by PW-14 and PW-05.

- 65% of particles released from the NWIRP recharge basins are captured by Grumman production wells, with 2% reaching the south constant head boundary. BWD well BP-11 receives 19%, BGD-1 receives 7%, BP-08 receives 6% and BP-09 receives 1% of the total particles released.

- The capture zones for BWD wells BP-07, BP-08 and BP-09 extend primarily into the north constant head boundary, although 8% of particles move from the Grumman north recharge basins to BP-08.

No Pumping Conditions at Grumman Production wells and Recharge basins

No pumping conditions were simulated to determine how contaminants would move if Grumman production wells and recharge basins were inactive, and no pumping activity was occurring at the Grumman site. For this pumping scenario, all Grumman production wells and recharge basins were inactive. Recharge basins on Hooker-Ruco property were considered inactive. Two separate scenarios were considered for past pumpage conditions at the BWD wells during no pumping conditions at the Grumman site (as shown in Table 10-1). Average pumping conditions and high pumping conditions for the BWD wells were simulated. These two pumping conditions for the BWD wells are the same as those used for the high pumping conditions at Grumman production wells and basins.

Particle Tracking Results and Conclusions- No Pumping at Grumman, BWD Wells at Average Pumping Conditions

- Particles released from Site 1 move to the south constant head boundary.

- The capture zone for BWD wells BP-07, BP-08 and BP-09 extends into the north constant head boundary.

Particle Tracking Results and Conclusions - No Pumping at Grumman, BWD Wells at High Pumping Conditions

- 42% of the particles released from Site 1 were captured by BP-10, and 58% were captured by BP-11

- The capture zone for BWD wells BP-07, BP-08 and BP-09 extends into the north constant head boundary.

10.1.9 Sensitivity Analysis

Sensitivity analysis is the process of characterizing the effects of changes in model parameters on the behavior of the calibrated model. Sensitivity analysis for the groundwater flow model included increasing and decreasing aquifer parameters incrementally and comparing the resulting changes in modeled heads to the calibrated values of head. The magnitude of change in heads from the calibrated solution is a measure of the sensitivity of the solution to that particular parameter. Additional discussion of sensitivity analysis procedures and results are presented in Section 9.0.

Horizontal hydraulic conductivity values were increased and decreased by 25% and 50% for the sensitivity analysis. Sensitivity analysis results for hydraulic conductivity show that a decrease of 50% results in a significant increase in both mean error and absolute residual, indicating the model results are sensitive to an decrease of greater than 25% of horizontal hydraulic conductivity compared to calibrated values. The model results are not highly sensitive to an increase of up to 50% or a decrease of up to 25% for horizontal hydraulic conductivity. However, while the model results may not be highly sensitive to changes in horizontal conductivity of this magnitude, these changes do produce less favorable solutions than the calibrated model.

Vertical hydraulic conductivity values were increased and decreased by 25% and 50% for the sensitivity analysis. Sensitivity analysis results show that the model is sensitive to a decrease of greater than 25% of vertical hydraulic conductivity. The model results are not highly sensitive to an increase of up to 50% and a decrease of up to 25% for vertical hydraulic conductivity. However, while the model results may not be highly sensitive to changes in vertical hydraulic conductivity of this magnitude, these changes do produce less favorable solutions than the calibrated model.

Storage values were increased and decreased by 25% for the sensitivity analysis. Storage values are used by MODFLOW only during transient simulations, therefore the effects of the sensitivity analysis results were determined by comparing the calibrated time-drawdown curves to the sensitivity analysis curves for the pump test #1 simulation. These curves indicate that the model results are sensitive to an increase of greater than 25% of the storage value and that the model is less sensitive to a smaller increase in storage of 25% or less.

Porosity values were increased and decreased by 25% for the sensitivity analysis. Porosity values are not used in the flow model, although they are incorporated into the particle tracking module MODPATH. Changes in porosity will not effect particle flow direction but will effect the travel time of the particle. Results show that there is a direct relationship between the porosity and the travel time of a particle moving through the aquifer. A 25% increase or decrease in porosity results in the same amount of change in the total travel time of a particle through the aquifer.

Recharge values were increased and decreased by 25% and 50% for the sensitivity analysis. Changes in the recharge to the system exhibit a linear relationship to the mean error and absolute residual values, with an equal amounts of mean error increase and absolute residual error increase being incurred regardless of weather recharge is increased or decreased.

To determine the effect of more distant boundaries on the capture zone of the eastern BWD wells (BP-07, BP-08, BP-09) the northern constant head boundary conditions in the MODFLOW model were moved 1400 ft to the north, a 40% increase in the distance from the BWD wells to the north constant head boundary. The results of the sensitivity analysis show that under average or high pumping conditions at the BWD wells the capture zone of these wells is not significantly increased if the north constant head boundary is moved 1400 ft north.

10.1.10 Summary of Modeling Results

The computer modeling performed for the NWIRP site accurately simulated water levels in 56 of 61 monitoring wells in the February, 1992 pumping condition and accurately simulated water levels in 55 of 61 monitoring wells in the August, 1992 pumping condition. The wells which fell outside the calibration criteria are in the immediate vicinity of active production wells or recharge basins, which may account for these disparities. Statistical analysis (linear regression and residual contour plots) performed on the calibrated steady-state model data indicates a nearly direct correlation in modeled and measured values of head, and that no significant trends exist in the distribution of model error.

Model simulation of pumping test #1 showed very similar results to data measured during the pumping test. A comparison of measured and modeled drawdowns (in the pumping well and the observation wells) shows very close agreement of measured and modeled data. In addition, the time-drawdown curves for modeled and measured data exhibit very similar results. The simulation of pumping test #2 was more difficult because of the small amounts of drawdown produced in the observation wells and due to the size of the model grid-blocks. Model simulations were within 1.0 ft of measured drawdowns for pumping test #2.

During model validation, the model was used to simulate water elevations for two months of data. The model accurately predicted water levels in 59 of 61 monitoring wells in the January, 1992 pumping condition and accurately simulated water levels in 54 of 61 monitoring wells in the August, 1992 pumping condition.

Sensitivity analysis was conducted for all aquifer parameters. Results indicate that the model is not highly sensitive to increases in horizontal or vertical hydraulic conductivity of up to 50% of calibrated values. The model showed significantly increased error if horizontal or vertical hydraulic conductivity were decreased more than 25% from calibrated values. Time-drawdown curves for shallow monitoring wells indicate that the model is sensitive to and increase in storage of 25%. Recharge and porosity exhibit linear (predictable) effects on model output. Sensitivity analysis indicates that moving the north constant head boundary 1400 ft to the north does not have a significant effect on the capture zones of the BWD wells BP-07, BP-08 and BP-09.

Table 10-3 summarizes particle tracking results form Grumman production wells and BWD wells, and when these wells are effected by particle releases. Particle tracking indicates that under current pumping conditions particles released from Site 1 will be captured by Grumman production wells, and BWD wells will not capture particles from the NWIRP recharge basins. Under high pumping (past) conditions at Grumman and average BWD rates, Site 1 particles are captured by Grumman production wells. A small number of particles may effect BWD well BP-08, and to a lesser extent, BWD well BP-09. If Grumman production wells and BWD wells pump at a high rate for sustained periods (as simulated by the steady-state model), all Site 1 particles are captured by Grumman production wells, and 19% of the particles released may move from the NWIRP recharge basins to BWD wells. These pumping conditions may have occurred for short time periods in the past, although the high pumping conditions may not have continued for extended periods of time as simulated in the steady-state model runs. Assuming no Grumman production well or recharge basin activity and average pumping conditions at the BWD wells, Site 1 particles move to the southern constant head boundary, and the capture zone of the BWD wells is not effected by NWIRP recharge basins. Under high BWD well pumping rates, particles released from Site 1 are captured by BWD wells BP-10 and BP-11.

TABLE 10-3

SUMMARY OF FORWARD TRACKING RESULTS

NWIRP BETHPAGE, NEW YORK

Grumman Pumping Rate	BWD Wells Pumping Rate	Particle Release Location	Wells Effected		
			Grumman Production Wells	Eastern BWD Wells (BP-7,BP-8,BP-9)	Southern BWD Wells (BP-10,BP-11)
Current Conditions	Average	Site 1	Y	N	N
		NWIRP Basins	Y	N	N
High Pumping	Average	Site 1	Y	N	N
		NWIRP Basins	Y	S	N
High Pumping	High	Site 1	Y	N	N
		NWIRP Basins	Y	Y	Y
No Pumping	Average	Site 1	N	N	N
No Pumping	High	Site 1	N	N	Y

Y = Well is effected by particles from release source (well captures more than 5% of the total amount of particles released.

S = Well is slightly effected by particles from release source (well captures less than 5% of the total particles released).

N = Well is not effected by particles from release source.

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